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Development of a Reservoir Embayment Characterization Process to Prioritize Water Quality Improvement.

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Development of a Reservoir Embayment Characterization Process to Prioritize Water Quality Improvement Efforts

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by

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ABSTRACT

Development of a Reservoir Embayment Characterization Process to Prioritize Water Quality Improvement

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To simplify water quality improvement in reservoirs, it has been suggested that efforts should be focused on smaller and more manageable units such as reservoir embayment areas. Embayments are prime locations to locate marinas, parks, beaches, and residential homes. Current data and information on reservoir embayments in Tennessee was assembled into a GIS-based database. Embayments of 11 main reservoirs were mapped and digitized in ArcGIS. Initial characterization criteria include watershed size, embayment area-watershed ratio, maximum residence time, and stream influence on embayments. The characterization process was then applied to the mapped reservoir embayments in Tennessee to identify and prioritize embayments that are most likely to be affected by watershed restoration efforts. This process has potential to used by resource agencies and stakeholders to prioritize water quality improvements in reservoir embayments.

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CHAPTER 1

INTRODUCTION

Background

The state of Tennessee has "over 60,000 miles of rivers and streams and over 90 publicly owned reservoirs and lakes totaling 538,000 lake acres" (TDEC, 2006). These waterways are home to a diverse population of aquatic species including over 80 federally and state threatened and endangered species (TWRA, 2006). In addition to harboring an array of aquatic life, these water bodies are important resources for drinking water, industries, and recreational activities throughout the state of Tennessee.

To protect Tennessee's valuable water resources, many agencies and watershed coalitions across the state have been actively working to improve water quality. These strong partnerships have already demonstrated watershed restoration successes in streams such as Crab Orchard Creek, a tributary to the Emory River, and Bullrun Creek, a tributary to the Clinch River (J. Hagerman, personal communication, April 15, 2007). Unfortunately, there are very few successful restoration projects to improve reservoir water quality. This is mainly due to the complexities of water quality management in reservoirs. Reservoirs tend to have large watersheds with multiple land uses, creating challenges in identifying and addressing causes and sources of pollution. In general, reservoir watersheds cover multiple jurisdictions ranging from communities to towns, counties, and states, which may cause disconnections among partnerships and water quality improvement efforts.

To simplify water quality improvement in reservoirs, it has been suggested that efforts should be focused on smaller and more manageable units such as reservoir embayment areas (Butkus, 1989). Embayments are back water areas created by the confluence of major tributaries and the main river channel of the reservoir (Figure 1). They are prime locations to locate marinas, parks, beaches, and residential homes. In fact, it has been estimated that over 50% of recreational uses in reservoirs occur in embayments (Meinert, Butkus, & McDonough, 1992). In addition, embayments have smaller contributing watersheds, making it easier to identify causes and sources of pollution. Stakeholders are able to gain ownership and focus on their improvement activities. For these reasons, it may be more feasible to investigate water quality improvements in embayments instead of entire reservoirs.

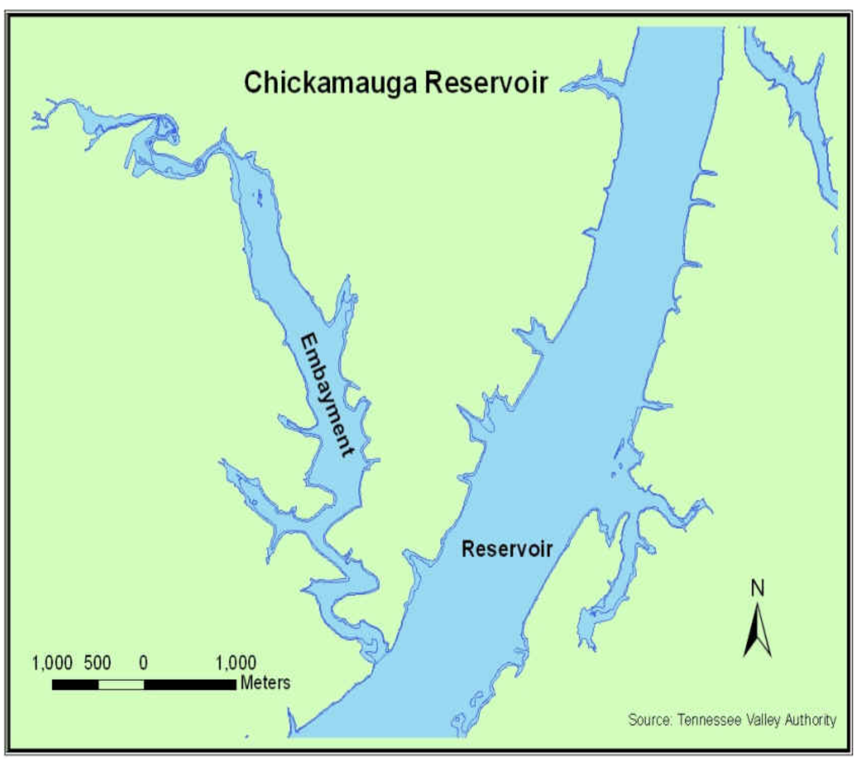


Figure 1. Example of a reservoir embayment on Chickamauga Reservoir

This project is the first step in focusing reservoir water quality improvements on embayments. 1) The primary goal is to review current data and information to determine which physical characteristics of embayments impact water quality. 2) This information will then be used to develop a model to prioritize and characterize water quality improvement efforts. 3) A long-term goal is to apply this model to reservoir embayments throughout Tennessee and calibrate it to verify and create a more effective tool to identify and prioritize embayments for resource management.

CHAPTER 2

LITERATURE REVIEW

TVA Research

Two projects laid the foundation for this research; the Reservoir Embayments as Potential Units for Water Quality Management (REPUWQM) and the Chickamauga Reservoir Embayment Study 1990 (CRES). Both were designed and implemented by the Tennessee Valley Authority (TVA). In the mid 1990s, TVA's reservoir assessments and water quality plans identified and emphasized the need to address impairments in reservoir embayments. With this information TVA recommended that embayments be viewed as potential water quality management units for reservoirs. This initiated preliminary TVA research on embayments and provided the background needed for this project.

As mentioned, the REPUWQM study is the foundation for several guiding principles used in this project. Butkus (1989) pointed out that in many cases reservoir embayments act differently from the main reservoir; in particular embayment water quality is usually different from main reservoir water quality. In addition, he suggested that embayment morphometry is a governing factor that affects water quality in embayments. Morphometry is the physical characteristics of the embayment such as depth, area, volume, etc. In conducting his research, he selected over 133 large embayments on several reservoirs throughout the Tennessee Valley and compiled morphometry data for each embayment. Cluster analysis was conducted to group the embayments based on their morphometry. Morphometry included embayment surface area, watershed area, watershed-surface area ratio, shoreline length, and shoreline development. He suggested that this categorization was just one example of how embayments could be grouped for management. To build on this research, it was recommended that additional data such as embayment depth, volume, and water quality be use to predict residence time and the embayments response to pollutant loadings (Butkus, 1989).

Butkus's research was a great first step in examing reservoir embayments as water quality management units. He identified several embayments throughout the Tennessee Valley and began to group them as a means of managing them. He recognized that residence time needed to be estimated because it is probably one of the most important morphometric features that impact water quality. He also suggested that water quality data should be collected in an effort to link and verify morphometric connections to water quality.

The CRES was TVA's next attempt in evaluating embayments. It focused on assessing water quality and aquatic resources in 15 major embayments in Chickamauga Reservoir. Physical, morphologic, and biological conditions such as fish, benthic macro invertebrates, dissolved oxygen, trophic status, and sediment were assessed for each embayment. According to Meinert et al. (1992) these assessments indicated that nutrient loadings could be estimated using land use classifications for the watersheds. They identified that chlorophyll-a concentrations correlated with total phosphorus concentrations. Aquatic macrophytes correlated with water clarity. Benthic fauna correlated well with trophic status. Fish abundance correlated with macrophyte coverage. In addition, it was agreed that embayment depth and retention time were major factors that affect water quality. Depth affects volume, retention time, vegetation growth, pollution accumulation, and other embayment physical characteristics. They also determined that most embayments exhibited different water quality characteristics from the main reservoir, reservoir embayments should be considered in water quality management, and similar assessments should to be conducted on other reservoirs.

As stated these two TVA assessments are the foundation for this research project. TVA began looking at embayments as potential management units when it identified that embayment water quality is normally different from the main reservoir water quality. Butkus identified several embayments across the Tennessee Valley and grouped them by characteristics in an effort to begin developing management efforts for each group. Meinert et al. (1992) actually tried to link embayment physical characteristics to water quality on Chickamauga reservoir and were fairly successful. In fact, the Chickamauga research was used to help calibrate the decision tree model for the current project.

Physical Characteristics That Impact Water Quality

In reviewing information on reservoirs, several physical characteristics were identified as impacting water quality. One of the most frequent characteristics mentioned is watershed size, the land area that drains all the surface water to the embayment. Reservoirs with larger watersheds are thought to have greater impact on water quality, this is because larger watersheds normally have more stormwater run-off and a higher potential for nonpoint source pollution (Holdren, Jones, & Taggart, 2001). In addition, watershed size also can impact hydraulic residence time. This is the time it takes for a reservoir to renew its water volume. If the watershed is large and the embayment is large, then the residence time will be long, providing more time for pollutants and nutrients to accumulate (Holdren et al.). Other impacts associated with the watershed include the geology and soil type. This influences the amount and type of minerals, nutrients, and sediments that enter the reservoir. Too much of either could have negative impacts on the reservoir ecosystem (Holdren et al.).

Embayment morphometry has a significant impact on water quality. Morphometric features include the surface area, depth, volume, and shoreline length. Surface area determines the amount of activity that can occur in an embayment. For instance, an example of human activity is recreation, which can have a significant impact on water quality. An example of natural activity is wind action, wind contacts the surface and influences dissolved oxygen levels (Holdren et al., 2001). Depth influences water stratification, plant growth, and algae growth. Volume impacts residence time and dilution of pollution. Shoreline length influences the amount of development that occurs along the shoreline (Holdren et al.).

CHAPTER 3

RESEARCH METHODS

Research Plan

In preparation, a project plan was developed for this project. Step (1) was to consult with an agency advisory committee, which was made up of the Tennessee Valley Authority (TVA) and the Tennessee Department of Environment and Conservation (TDEC). This committee provided insight and guidance on the project scope. Step (2) was to develop a research design for a database; deciding on the type of software and structure needed for the project. Step (3) was to collect existing data, both spatial and water quality data needed to be gathered. Step (4) was to develop a geodatabase, a place where the data could be stored and analyzed. Step (5) was to develop the decision tree model, a list of questions designed to identify priority embayments. Lastly, Step (6) was to use the decision tree model to prioritize embayments on 11 reservoirs in Tennessee. Below is a description of each step.

Consult with Agency Advisory Committee

In addition to the literature review, representatives from the Tennessee Valley Authority (TVA) and Tennessee Department of Environment and Conservation (TDEC) provided invaluable information and support. TVA manages the nation's fifth-largest river system; owning and operating over 39 reservoirs to minimize flood risk, produce power, maintain navigation, provide recreational opportunities, and protect water quality in the 41,000-square-mile watershed (Anderson, 2006). TVA water quality practitioners are very interested in managing water quality in reservoirs; in fact, they currently work with partners and communities to improve water quality in targeted watersheds and reservoirs. As can be seen in the literature review, TVA investigated the potential of using reservoir embayments as management units in the past 2 decades (Butkus, 1989; Meinert et al., 1992).

TDEC is responsible for managing Tennessee's waters to meet federal and state designated uses. To do this they assess streams and reservoirs to identify water quality issues. They regulate point source pollution such as discharges from industry. In addition, they partner with the community and natural resource agencies to implement water quality improvement efforts for nonpoint pollution (TDEC, 2006). For these reasons TDEC is interested in assessing and managing water quality in Tennessee reservoirs.

Research Design and Methodology

Gao at ETSU developed GIS-based Karst Feature Database (KFD) and watershed management databases with three interactive modules: spatial operation, spatial analysis, and hydrologic modules (Gao, 2007; Gao & Alexander, 2007; Gao, Alexander, & Barnes, 2005a; Gao, Alexander, & Tipping 2005b; & Gao, Tipping, & Alexander, 2006). The prototype and modules of the KFD and watershed management database was modified to fit the research and management goals for this project to prioritize embayments in Tennessee. Available geographic, geologic, and hydrologic data related to embayment and watershed investigations in Tennessee were entered into the database (more information about the data is located in Data Collection and Development). The distribution of these features was manipulated using spatial operation and spatial analysis modules in ArcMap 9.2. Butkus first attempted to characterize embayments by using morphometry (watershed size, embayment area, shoreline development, volume, etc) in 1987. Recognizing that there was limited information available for Butkus's research, this project is an attempt to expand Butkus's research by including embayments in tributary reservoirs, determining max depth and estimate volume in order to develop a maximum residence time index. In addition, existing water quality data collected by TVA were used to evaluate physical characteristics of the embayments.

Data Collection and Development

Spatial data were collected from the TDEC, TVA, and Fishing Hotspots to create a Geographic Information System (GIS) personal database. Spatial coverages for Tennessee counties, streams, watersheds, and impaired streams all came from the State of Tennessee's Spatial Data Server locate at http://www.tngis.org/index.htmlwebsite. Reservoir coverages were provided by the TVA (Figure 2) and bathymetry data came from Fishing Hotspots Inc, a private company that produces digital lake and reservoir maps for profit (Figure 3). All but the bathymetry data were public information. Fishing Hotspot required a nondisclosure agreement with ETSU. At the time of this project bathymetry was only available through commercial companies.

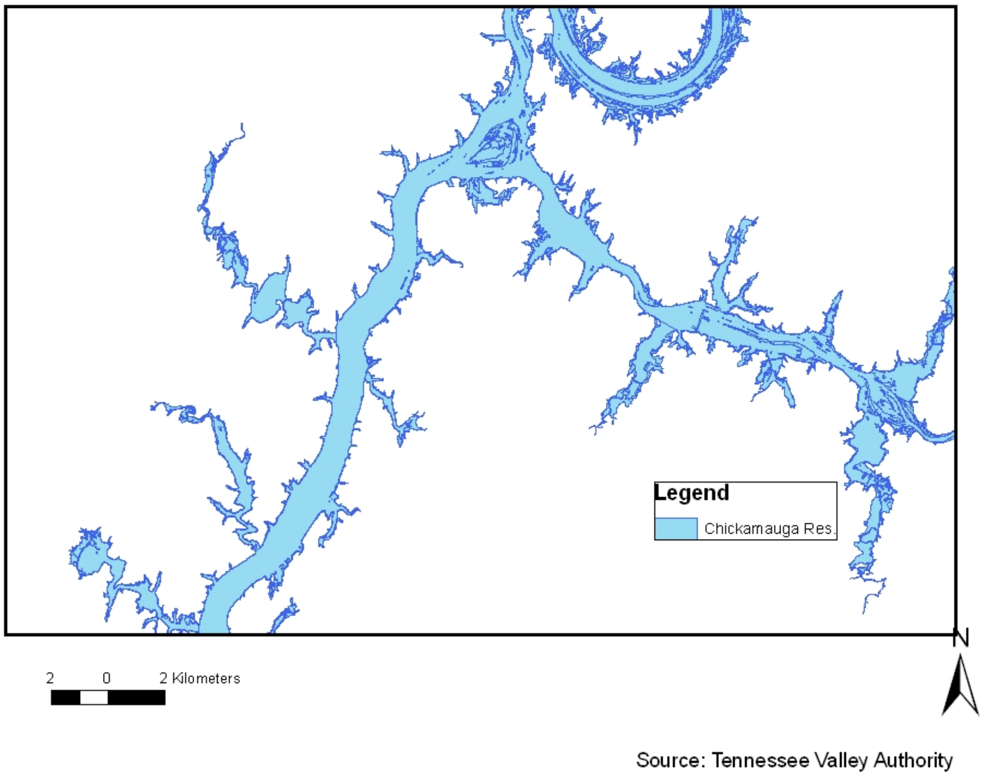


Figure 2. TVA Reservoir data layer

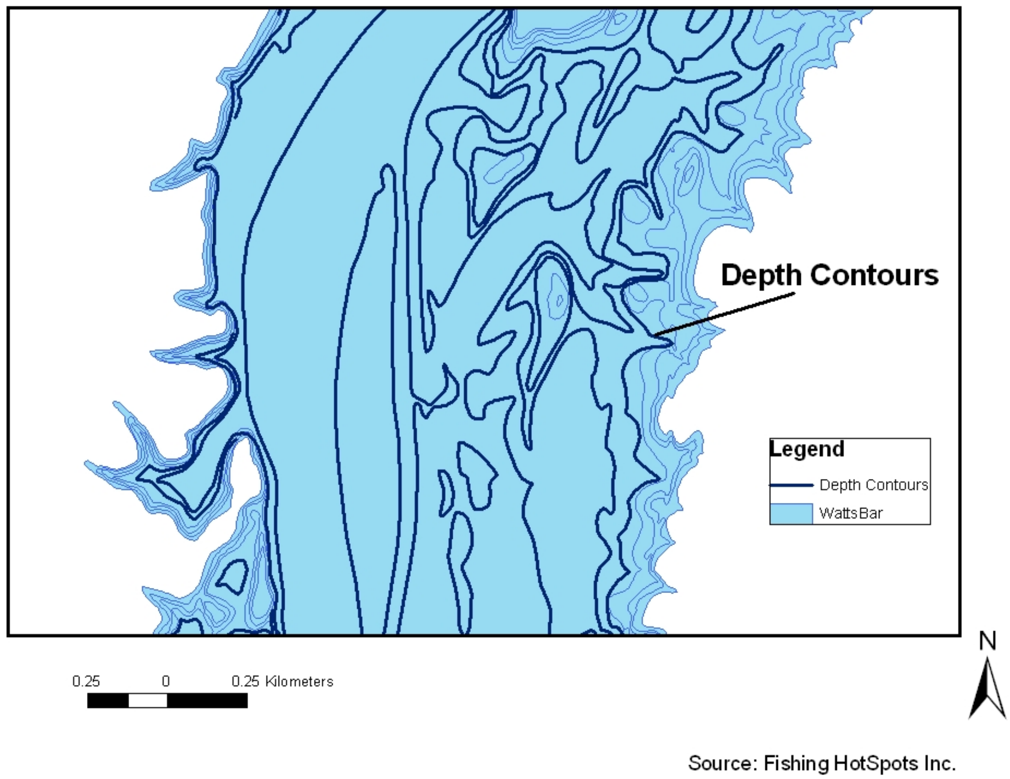


Figure 3. Fishing HotSpots bathymetry data layer

Water quality data were gathered from TVA. During the summer of 2005, TVA collected water chemistry data in several reservoir embayments in the Tennessee Valley (Baker, 2006). These data were entered into the personal database and used to further evaluate which physical characteristics impact water quality.

In addition to the spatial data and water quality data, the Fishing HotSpots maps were used to generate maximum depths for each embayment. There data were then entered into the database and used in the prioritization process.

Data Layer Development

Two additional data layers were developed for this project; the reservoir embayment layer and embayment watershed layer. The data layer for reservoir embayments was created using ArcMap 9.2. Because there is no recognized set of criteria or definition for reservoir embayments, this research defines them as back water areas created by the confluence of major tributaries and the main river channel of the reservoir. They were selected by manually identifying a tributary stream, identifying a significant backwater area, and then estimating a watershed-drainage area size larger than three square miles (watershed size and cutoffs are described in more detail in the Node Description section). Embayments were delineated using the TVA reservoir base map. In ArcMap, the cut polygon feature was used to cut the embayment polygons. The polygons were cut at the point where the backwater areas met the main reservoir (Figure 4). Ninety-six embayments were identified and delineated (Table 1).

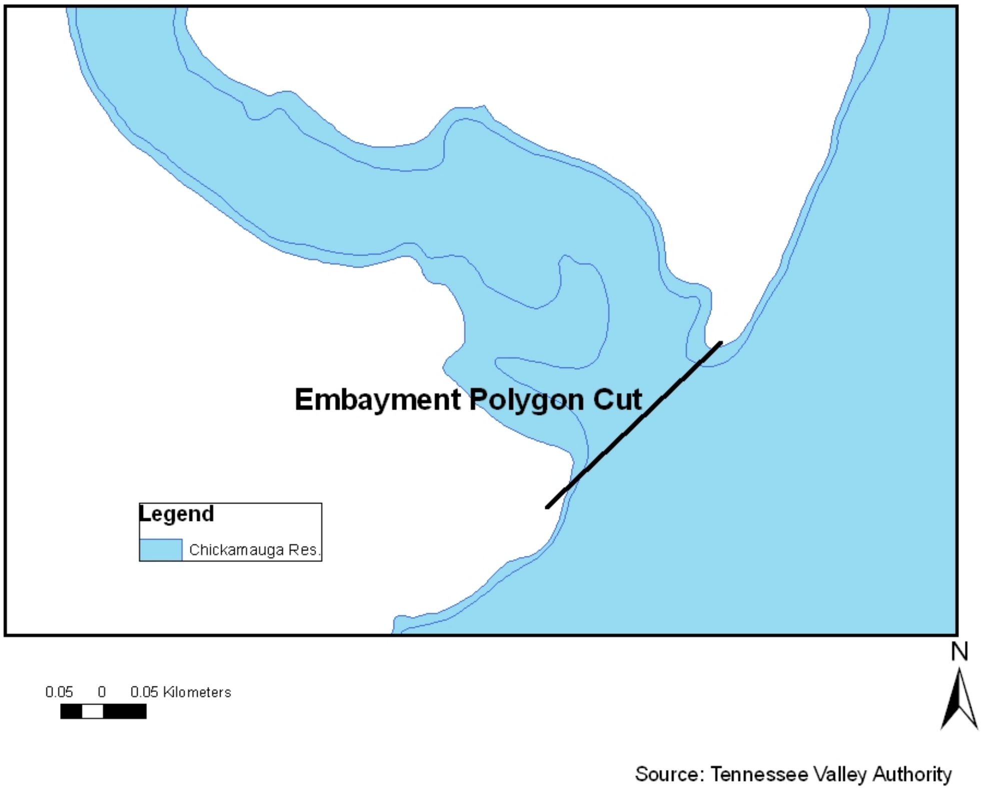


Figure 4. Polygon cut for embayment delineation

The embayment watershed layer was created by using a web-based GIS application called TN StreamStats. This web-based application was developed by the U.S. Geological Survey and Environmental Systems Research Institute (ESRI) to provide users (engineers, planners, scientists) with an assortment of tools to plan and manage water resources (Ladd & Law, 2007). The application can estimate stream flow statistics, delineate watersheds, and determine several other basin characteristics.

Table 1. Number of Identified Embayments

Reservoir	**Number of Embayments**
Boone	6
Cherokee	9
Douglas	6
Norris	17
Chickamauga	18
Nickajack	1
Tims Ford	9
Watts Bar	7
Tellico	10
Fort Loudon	9
Kentucky	4
Total	96

After the embayments were identified and delineated in ArcMap, watersheds for each embayment were then delineated in TN StreamStats. The website was accessed at the following address (http://streamstats.usgs.gov/tnstreamstats/index.asp) (Figure 5). After the user zoomed to the embayment and selected the "watershed delineation" button, a curser was used to select the endpoint of the watershed or the mouth of the embayment, the program then delineated the watershed (Figure 6). The delineated watershed was checked for accuracy by observing if the watershed boundary followed topographic divides. In some cases the watershed boundary had to be adjusted by using the adjustment function in StreamStats. The "StreamStats" button was then used to generate flow statistics for each watershed (basin characteristics, peak flows, low flows, etc.). This information is based on collected data from surrounding stream gages and is generated by built in regression equations and prediction methods (Ladd & Law,2007). The information was then saved as a shape file. The shape file was in the same coordinate system as the reservoir base layer (NAD_1983_StatePlane_Tennessee_FIPS_4100_Feet). All saved shape files for each embayment were then merged into one shape file for each reservoir.

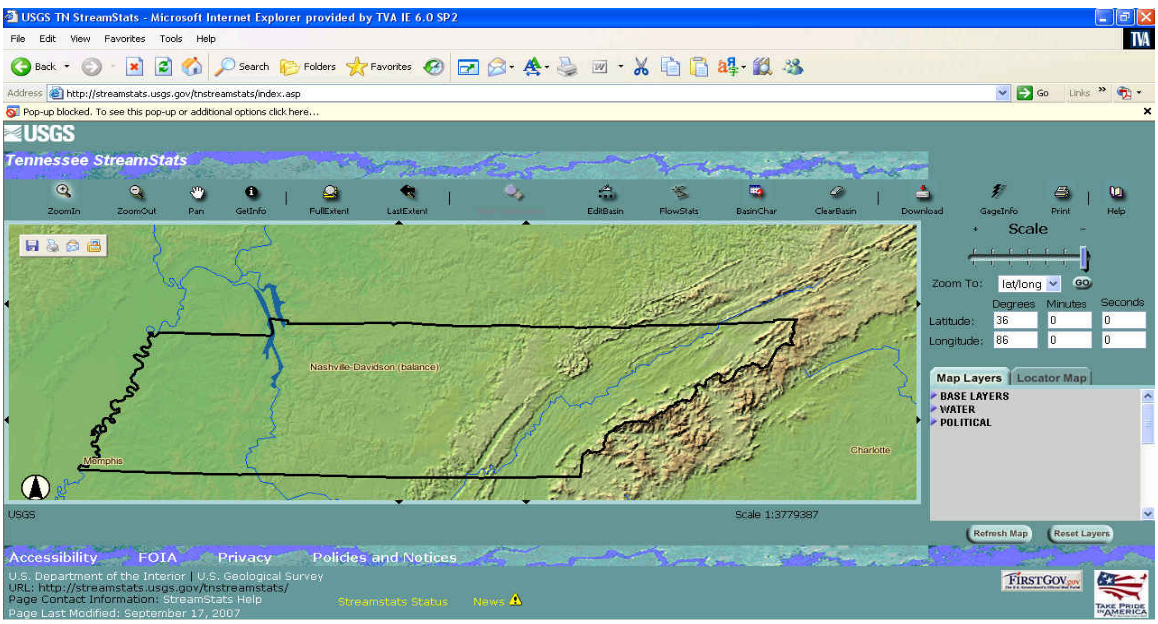


Figure 5. StreamStats Interactive Screen

(adapted from http://streamstats.usgs.gov/tnstreamstats/index.asp, December 18, 2008)

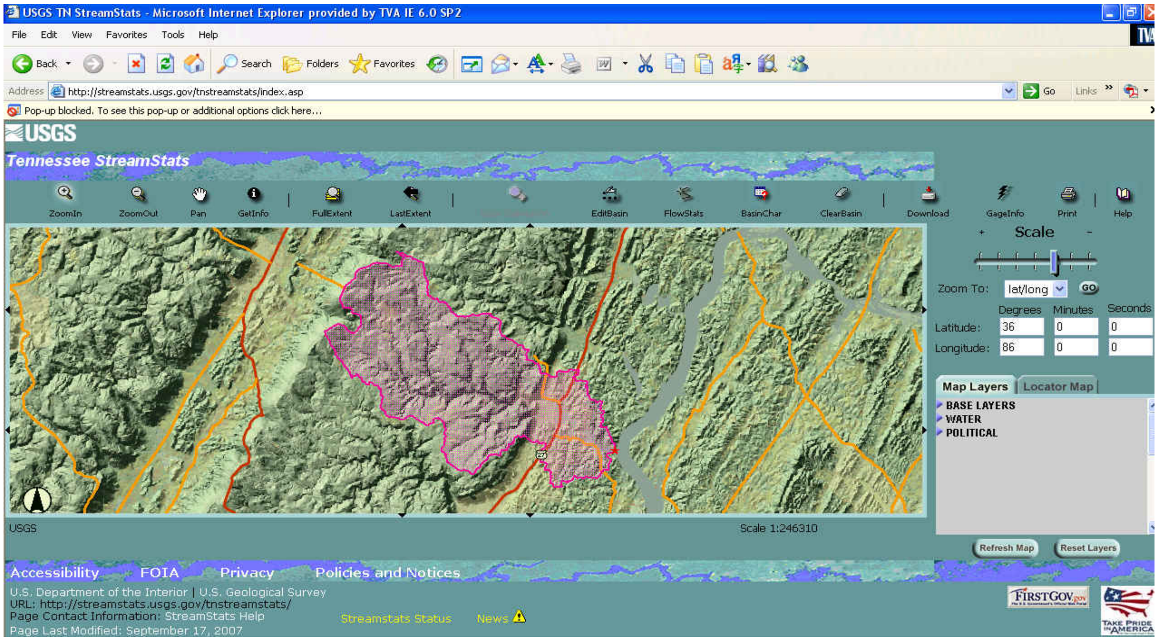


Figure 6. Embayment Watershed Delineation

(adapted from http://streamstats.usgs.gov/tnstreamstats/index.asp, December 18, 2008)

<u>Challenges</u>

It was a challenge to find a detailed and consistent map for all Tennessee reservoirs. After reviewing several datasets, it seemed that TVA had the most consistent set of maps. The only problem was the reservoir maps had been created through combining or connecting several different maps (Figure 7), which segmented the reservoirs and embayment polygons. This made it difficult to run calculations on the polygons; all the embayment polygons had to be summed. To fix this one embayment polygon had to be created by merging all the segments into one (Figure 8). To merge polygons in ArcMap, two polygons were selected; the “Start Editing,” button was clicked; the target -name of reservoir was filled in; and “Task-Modify Feature” was clicked. ArcToolbox was opened, then the user navigated to "Data Management Tools" function; "General " function; and "Merge" function. The polygons were then merged.

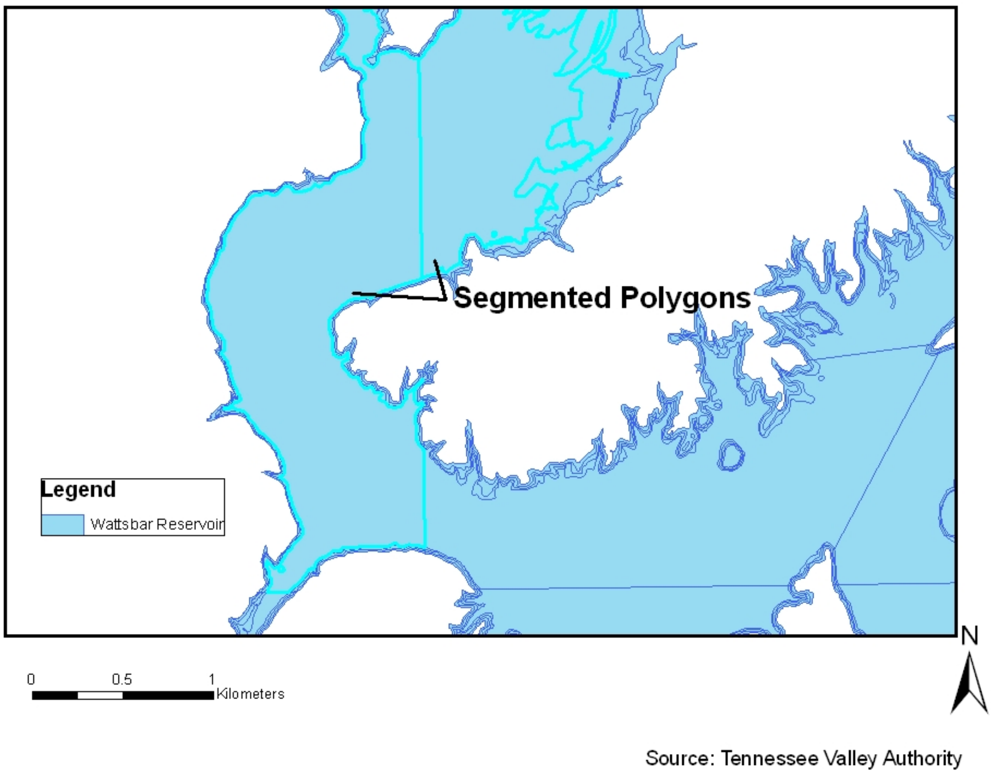


Figure 7. Example of segmented polygons

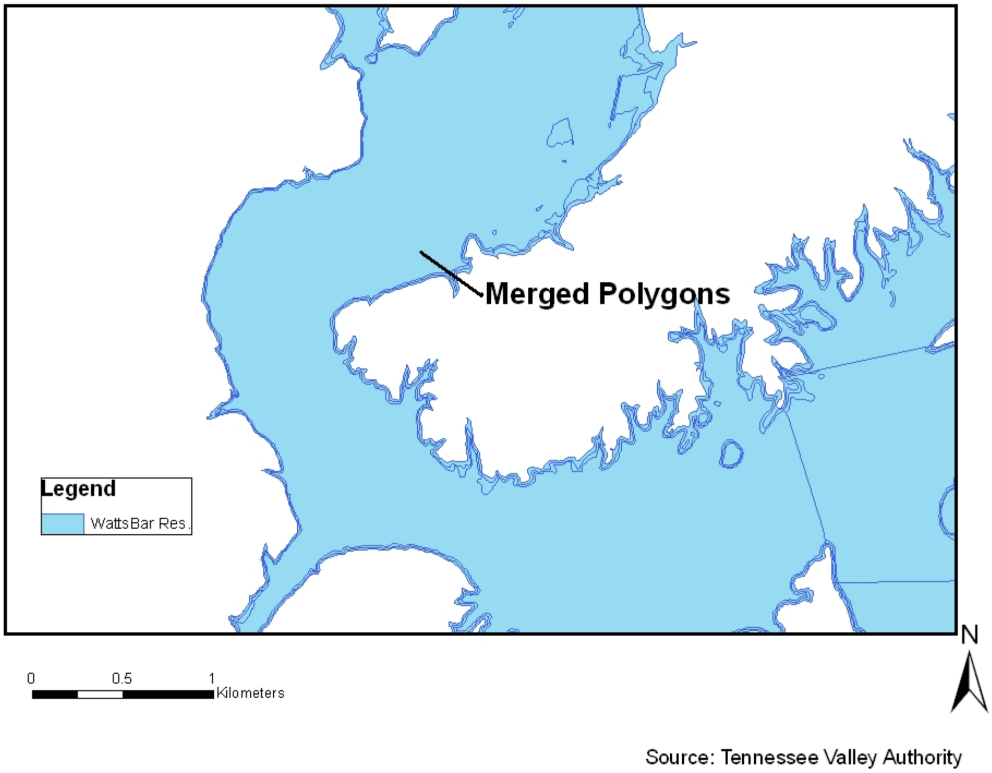


Figure 8. Example of merged polygons

The embayment had to be further edited by merging the under water contour polygon with the normal pool contour polygon. The TVA reservoir maps had under water, normal pool, and maximum shoreline contour polygons (Figure 9). The under water contour identifies the water elevation at winter pool, which is normally the lowest elevation of the year. The normal pool contour identifies the water elevation during summer pool; which is normally the highest elevation of the year except during flood events. The maximum shoreline contour identifies the elevation at which TVA has the right to flood. By merging the under water and normal pool contour polygons, one polygon was created for the normal pool elevation (Figure 10).

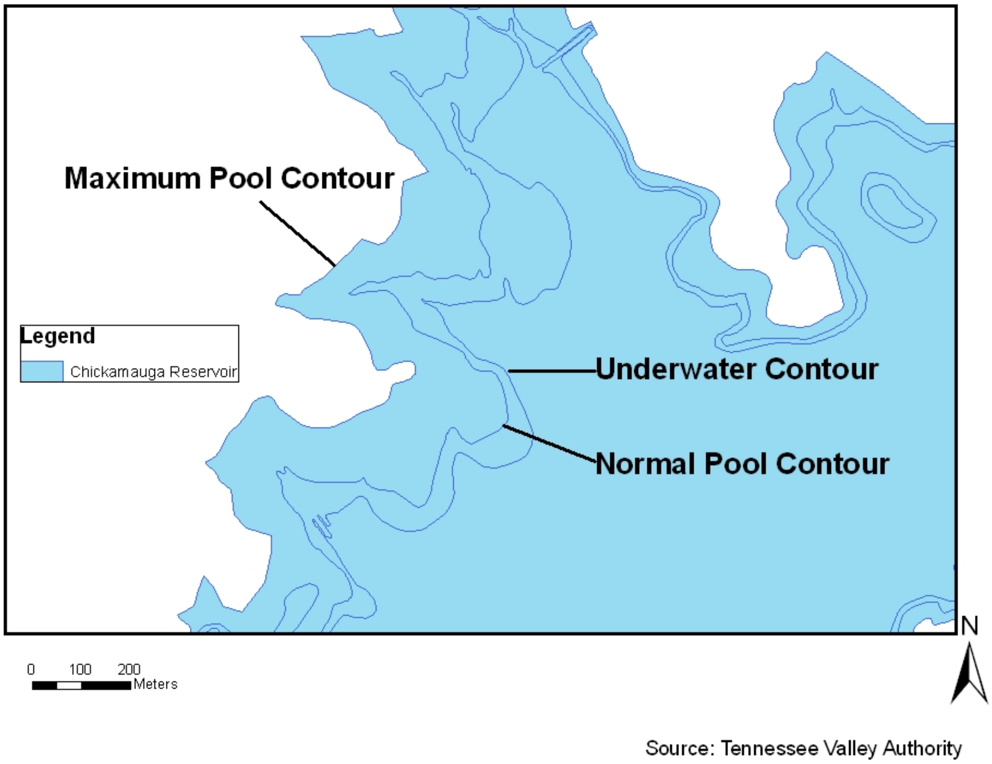


Figure 9. Example of reservoir contours

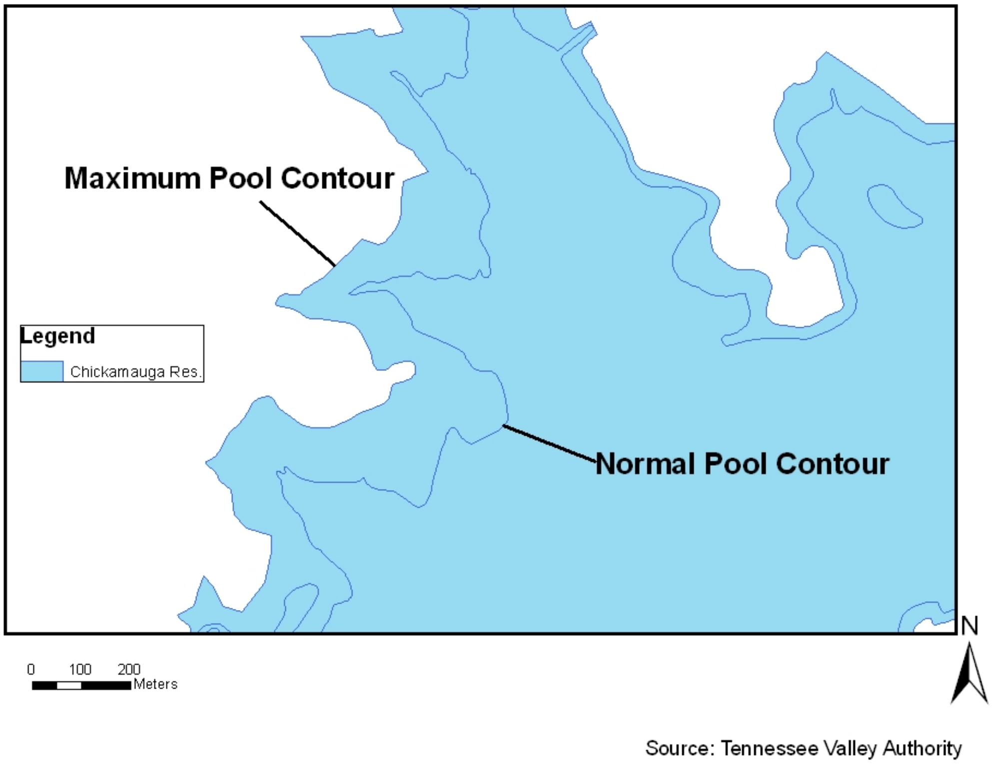


Figure 10. Merge of normal and underwater contours to create one polygon

In order to merge the two polygons in ArcMap, the two polygons were selected; the "Start Editing" function, "target reservoir" function, and "Task-Modify Feature" were then selected. ArcToolbox was opened, then the user navigated to "Data Management Tools," "General," and "Merge." The polygons were then merged.

Personal GeoDatabase

A personal geodatabase was developed to manage the data for this project. Personal databases were designed for the management of datasets that are small (under 2 GB) and used by small work groups (ESRI, 2008.). All contents of the database are managed by Microsoft Access and are tied to Windows operating system (ESRI, 2008).

This database was developed based on the Karst Feature Database (KFD) and watershed databases created by Gao, the ETSU project manager for this project. They have three interactive modules: spatial operation, spatial analysis, and hydrologic modules (Gao, 2007; Gao & Alexander, 2007; Gao et al., 2005a, 2005b, 2006). The prototype and modules of the KFD and watershed management database were modified to fit the research and management goals to prioritize embayments in Tennessee. Available geographic and hydrologic data (refer to the data Collection and Development section of this document) associated with reservoir embayments were entered into the database. The distribution of these features was manipulated using spatial operation and spatial analysis modules. The benefits of this database include the ability to perform different analysis, model environmental impacts, and develop maps and visual aids for communicating needs and impacts. All of this can be used for better planning and decision making (ESRI, 2008).

The objectives are to enhance embayment characterization with geographic information with existing datasets of water quality data, embayment depth, embayment area-watershed area ration, and watershed size. The characterization model or decision tree model (for more information refer to decision tree model section in this document) developed by this project will also be further tested and validated with ongoing water quality monitoring and field observations.

Database Documentation

It is essential to document the database development to assist researchers and practioners in duplicating and improving water quality management. Below is a list of actions and properties used to develop the personal GeoDatabase. If more information or details are needed for the ArcGIS 9.2 functions and operations; please refer to ArcGIS Desktop help online - http://webhelp.esri.com/arcgisdesktop/9.2/index.cfm?TopicName=welcome.

Step 1: The database was created by, opening ArcCatalogue, selecting an address where the database will reside, and clicking on the "new personal geodatabase" option. ArcCatalogue then created a new geodatabase. For this project the database was named EMB_GDB.mdb (Figure 11).

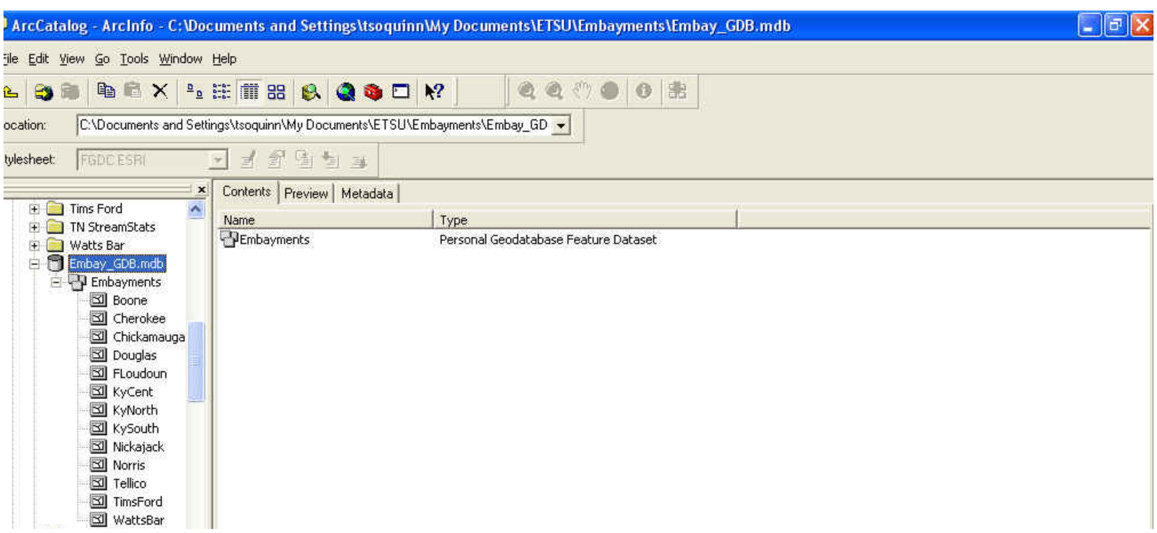


Figure 11. Creation of personal geodatabase

(adapted from ArcMap 9.2, January 18, 2009)

Step 2: The next step was to define the properties of the database. To do this, the user selected the database file (EMB_GDB.mdb). While still in ArcCatalogue, the user selected the "properties option," opening the database properties view. The domain tab was selected and domains were added. Domains are rules applied to the database. This database has five main domains; Geometry, Impaired, Max_Depth, Morph, and Water Quality. Information about the five domains is listed below.

In the database, the Geometry Domain description is "area and length," the properties include: Field Type - Double; Domain Type- Range; Minimum Value - 0; Maximum Value – 9, 999,999,999,999; Split Policy - Geometry Ratio; and Merge Policy - Sum Values (Figure12). This domain is applied to attributes such as area and length to ensure geometric consistency.

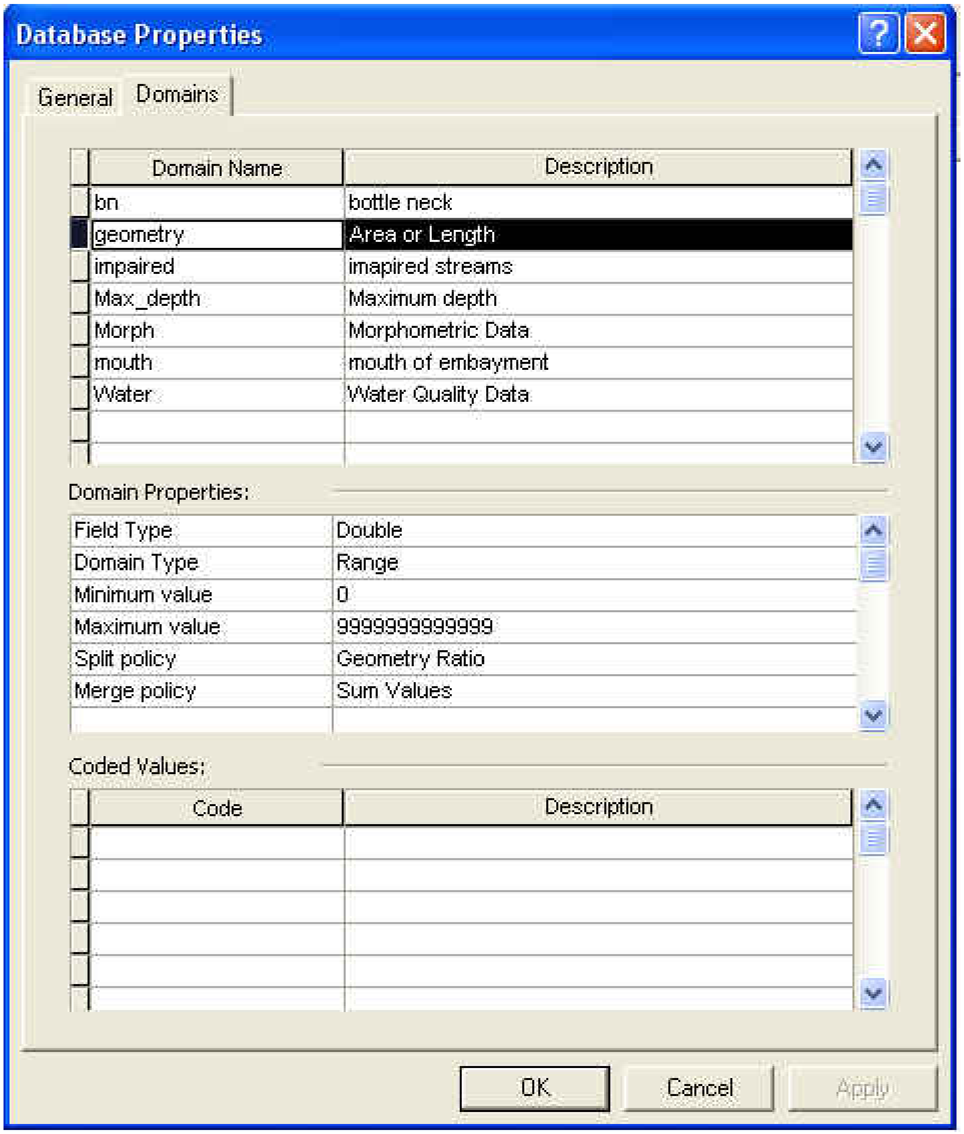


Figure 12. Geometry Domain and Properties

(adapted from ArcMap 9.2, January 18, 2009)

The Impaired Domain description is “impaired streams.” The properties include: Field Type - Text; Domain Type- Coded Values; Split Policy - Default Value; and Merge Policy - Default Value (Figure 13).

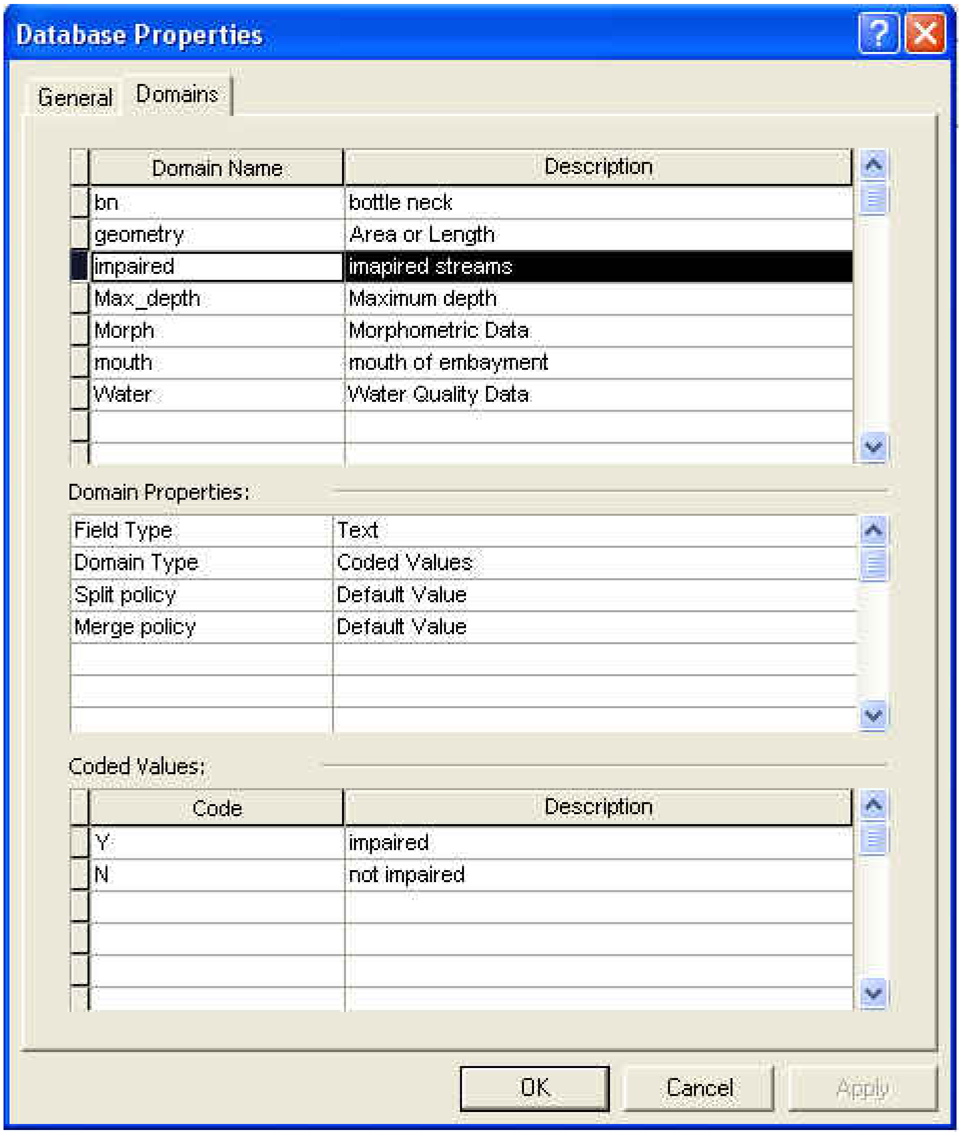


Figure 13. Impaired Domain and Properties

(adapted from ArcMap 9.2, January 18, 2009)

The Max_Depth Domain description is “maximum depth.” The properties include: Field Type - Short Integer; Domain Type- Range; Minimum Value - 0; Maximum Value - 300; Split Policy - Duplicate; and Merge Policy - Weighted Average (Figure 14).

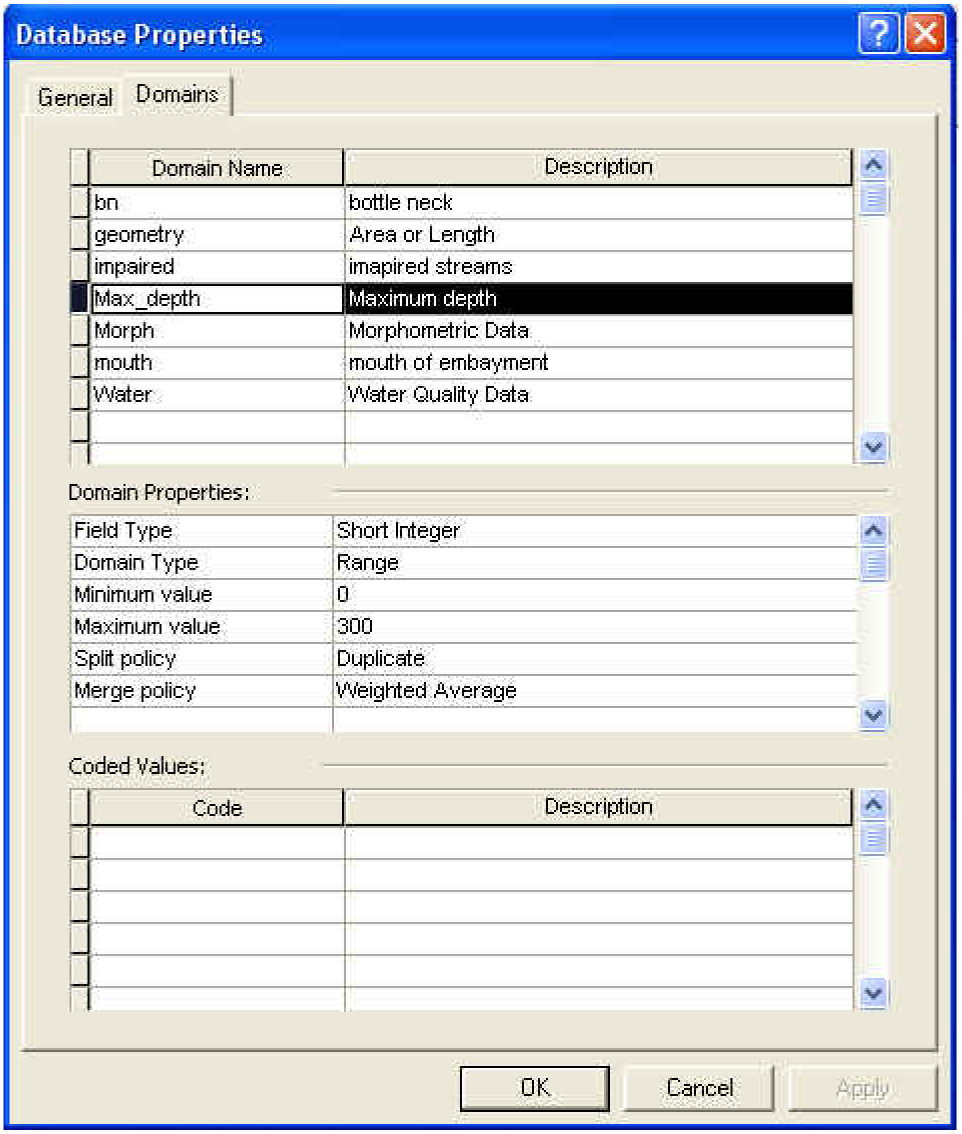


Figure 14. Max_Depth Domain and Properties

(adapted from ArcMap 9.2, January 18, 2009)

The Morph Domain description is "morphometric data," the properties include: Field Type - Double; Domain Type- Range; Minimum Value - 0; Maximum Value - 9999; Split Policy - Duplicate; and Merge Policy - Weighted Average (Figure 15).

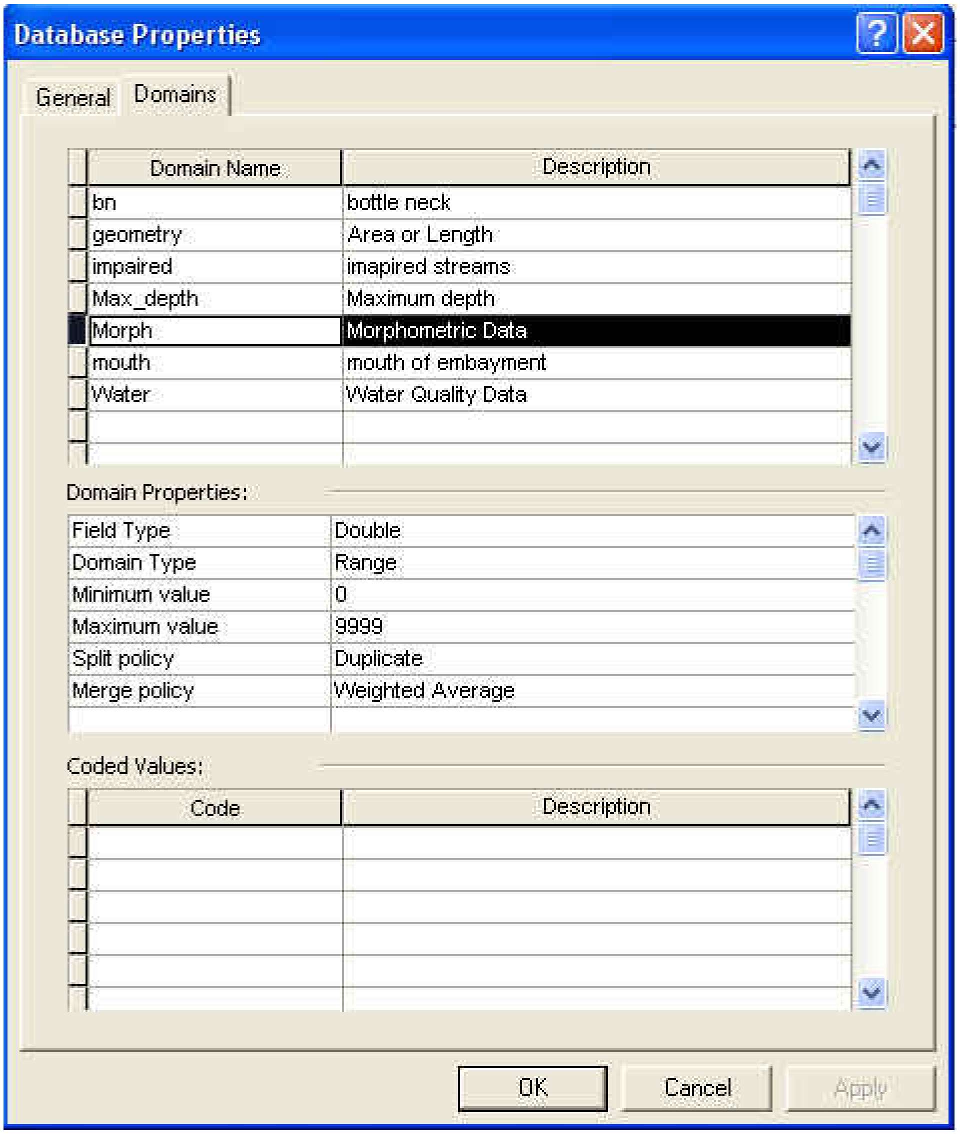


Figure 15. Morph Domain and Properties

(adapted from ArcMap 9.2, January 18, 2009)

The Water Domain description is "water quality data," the properties include: Field Type - Double; Domain Type- Range; Minimum Value - 0; Maximum Value - 9999; Split Policy - Default Value; and Merge Policy - Weighted Average (Figure 16).

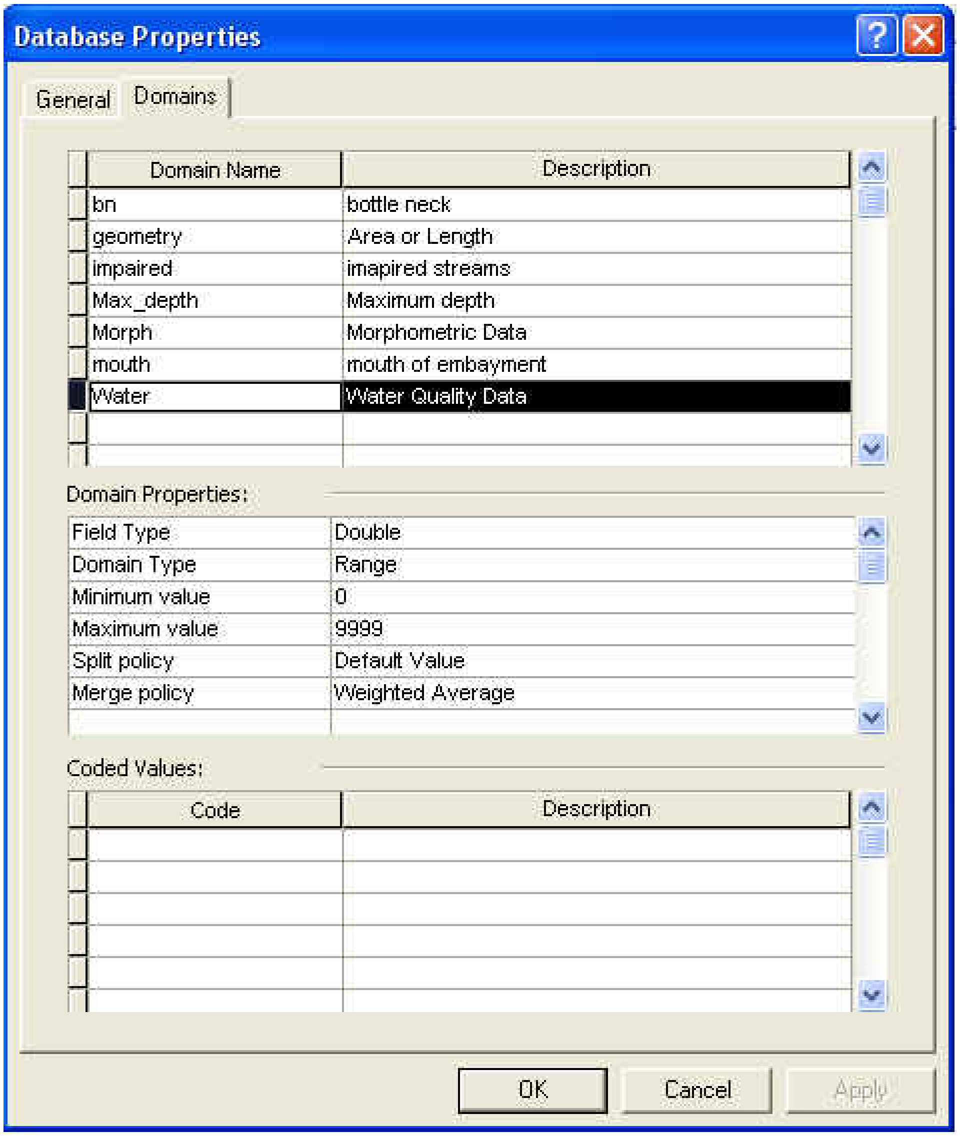


Figure 16. Water Domain and Properties

(adapted from ArcMap 9.2, January 18, 2009)

Step 3: A subfolder was then created in the database called Embayments. Under the Embayments folder, additional folders were created for each reservoir. Reservoirs included: Boone, Cherokee, Chickamauga, Douglas, FLoudon, Kentucky, Nickajack, Norris, Tellico, TimsFord, and WattsBar. Data coverages for each of these reservoirs were saved in the database. To do this, ArcCatalogue was opened; the user right clicked on the Embayment subfolder and then selected “Import” and “Feature Class (single).” The “Feature Class” screen opened and within the “input feature box” the user navigated to the folder where the reservoir data layer resided and selected the reservoir shape file such as Chickamauga shape file. The user then navigated to the “Output feature” box and selected the address at which the data should be saved, which was EMB_GDB.mdb\Embayments (Figure 17). The “Expression” box was selected and the user typed in RName=’Chickmauga’. The “Output name was Chickamauga.” The data layer for Chickamauga was then saved in the database.

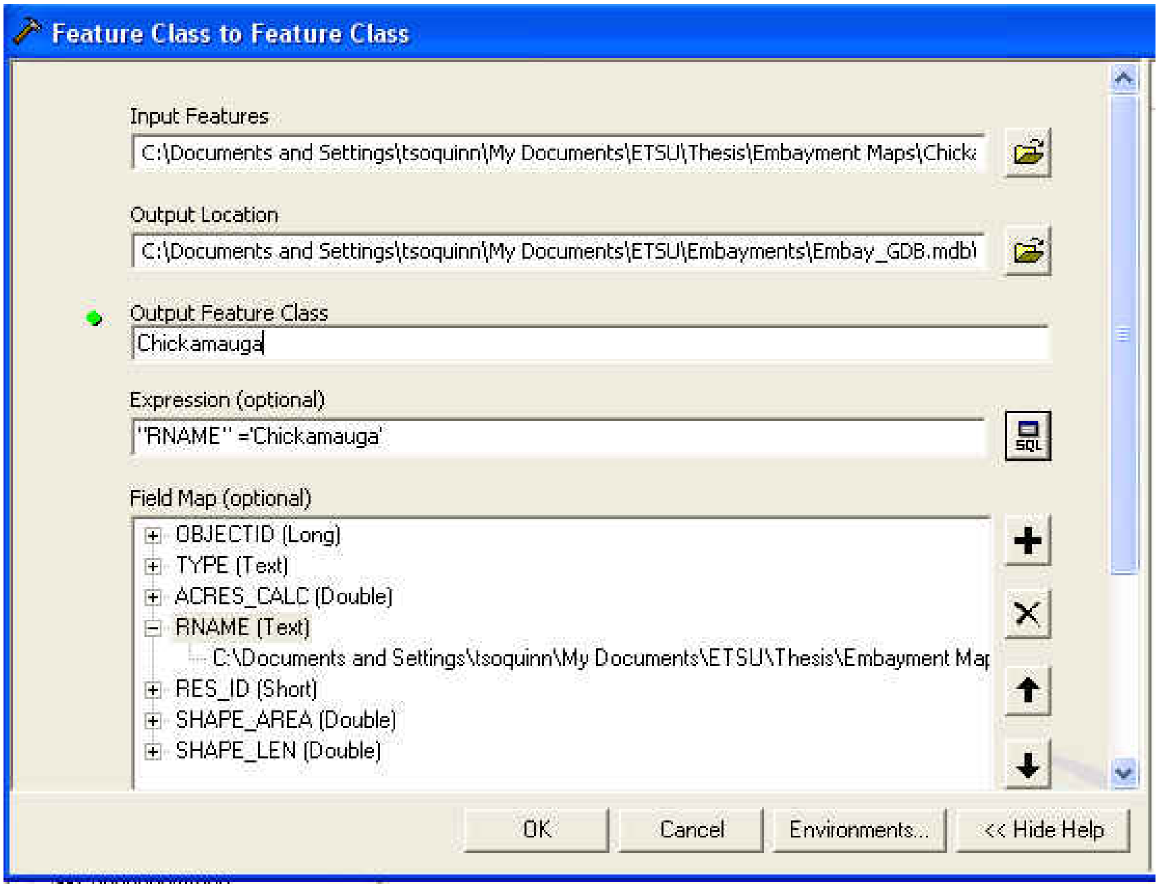


Figure 17. Import Feature Class for Chickamauga Reservoir

(adapted from ArcMap 9.2, January 18, 2009)

Step 4: Then next step was to define the properties for the reservoir components. All reservoir components have the same properties, so Chickamauga Reservoir properties were used as an example. Chickamauga was selected; the user right clicked and selected "properties." The "Feature Class Properties" view appeared and the Field tab was selected (Figure 18). Field names and properties were created as seen below (Table 2):

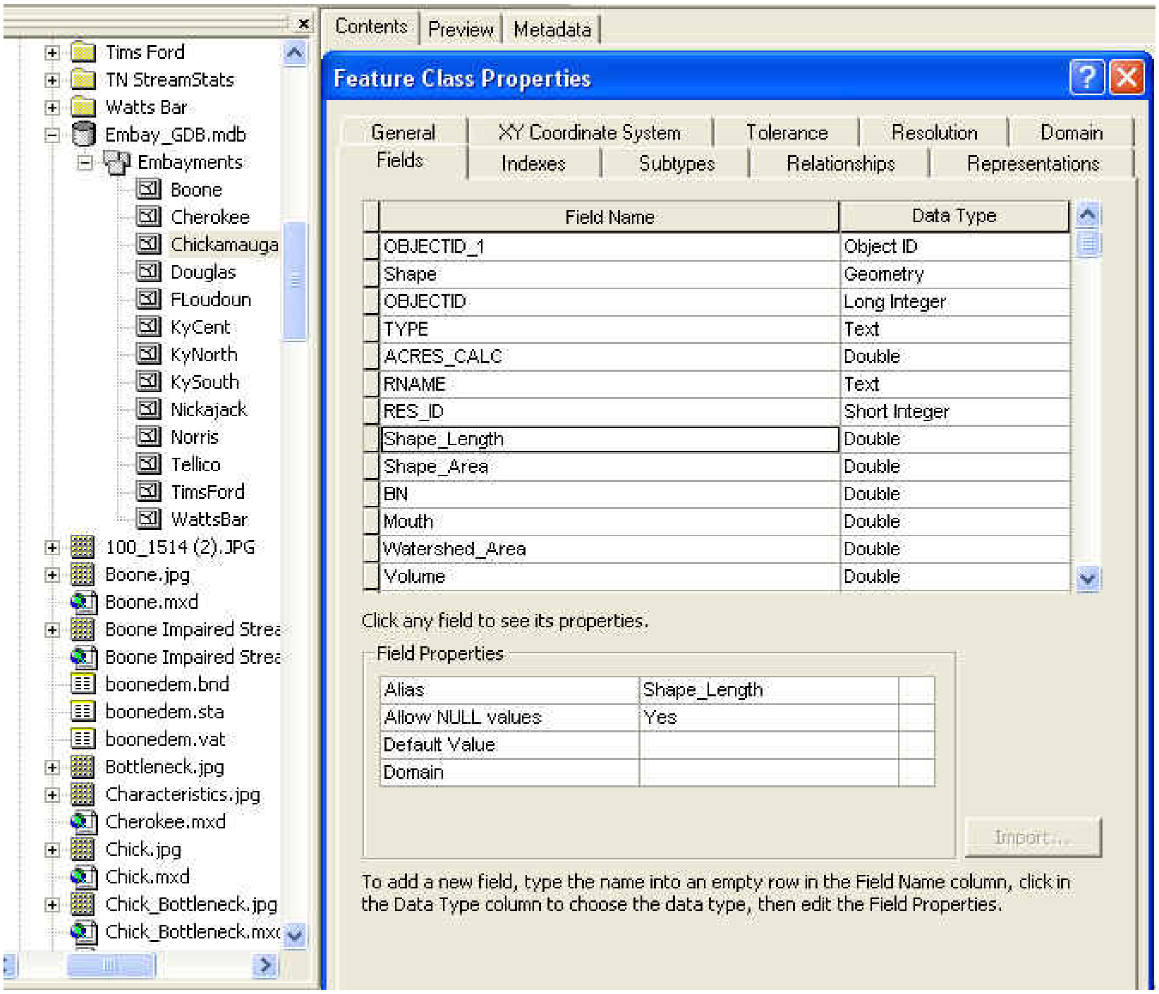


Figure 18. Feature Class screen for Field Name and Properties

(adapted from ArcMap 9.2, January 18, 2009)

Table 2. Database Field Names and Properties

Field Name	Data Type	Alias	Allow NULL Values	Default Value	Domain
Shape_Length	Double	Shape_Length	Yes	NA	geometry
Shape_Area	Double	Shape_Area	Yes	NA	geometry
Volume	Double	Volume	Yes	NA	morph
Min_Depth	Double	Min_Depth	Yes	NA	morph
Mean_Flow	Double	Mean_Flow	Yes	NA	
Mean_Residence	Double	Mean_Residence	Yes	NA	
Overflow_Rate	Double	Overflow_Rate	Yes	NA	morph
Temperature	Double	Temperature	Yes	NA	water
DO	Double	DO	Yes	NA	water
Total_N	Double	Total_N	Yes	NA	water
Total_P	Double	Total_P	Yes	NA	water
Chlorophyl	Double	Chlorophyl	Yes	NA	water
Turbidity	Double	Turbidity	Yes	NA	water
Fecal_Coli	Double	Fecal_Coli	Yes	NA	water
Suspended_Solids	Double	Suspended_Solids	Yes	NA	water
Max_Depth	short integer	Max_Depth	Yes	NA	Max_depth
Volume_Index	float	Volume_Index	Yes	0	
Watershed_Area	Double	Watershed_Area	Yes	NA	geometry

The above steps provided the bases for developing the embayment database. The documentation of these steps was saved for future users of the database. It is expected that newer versions of ArcMap may look different, but it is anticipated that the concepts will be similar.

CHAPTER 4

DISCUSSION

Decision Tree Analysis

When managing and analyzing an enormous amount of data such as this research does, users need the ability to sort and retrieve data to obtain information. The decision tree model is one of the most common methods to do this. The decision tree model can help manipulate data for spatial patterns and extract knowledge from large databases (Gao & Alexander, 2007). The tree is a hierarchical decision structure that asks crafted questions about attributes or characteristics of the data set. When the question is answered, a follow-up question is asked until a conclusion is met. The tree starts out with a root node, this is the basis of the decision; it has no incoming questions. Following the root node, there are internal nodes. These nodes have an incoming answer and two or more outgoing questions. There are also terminal nodes that have only one incoming answer and no out going questions (Quinlan, 1993). The decision tree for this project is attached (Figure 19). Each node is explained below.

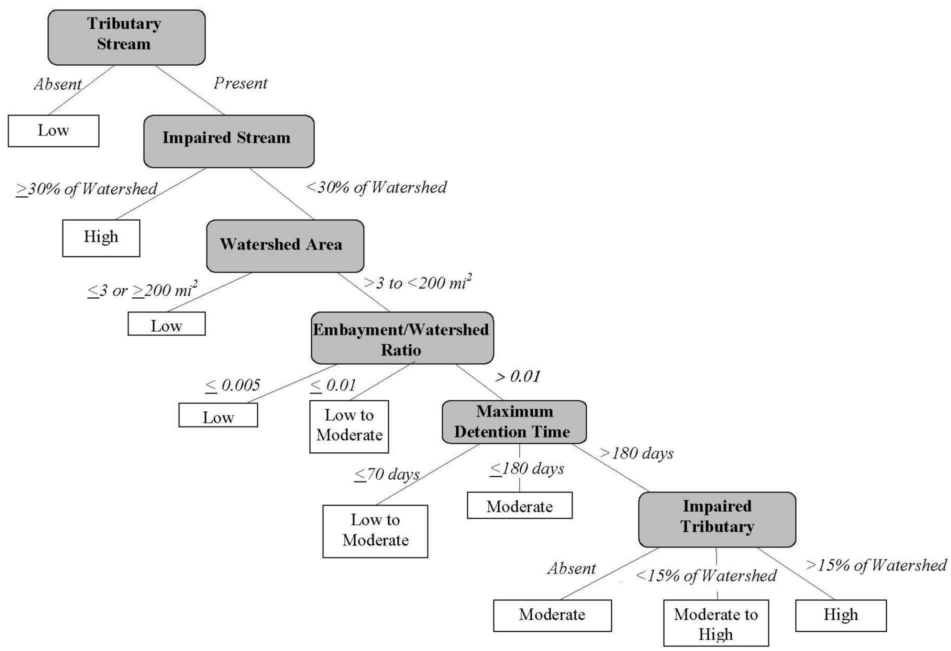


Figure 19. Decision Tree Model to prioritize embayment for water quality improvement

<u>Node Description</u>

Tributary Stream - This root node identifies whether the reservoir embayment has a feeding stream. If there is no tributary stream, it is assumed that the area is probably just a shoreline indentation along the main reservoir, not an embayment. In most cases the watershed above would be very small, which would indicate lower potential for nonpoint source pollution (Holdren et al, 2001). There are always exceptions, but for this project, the assumption is made.

The determination of a tributary streams was made by using ArcMap. A potential embayment was delineated and then a visual assessment was used to determine if the potential embayment had a tributary stream. If the embayment area did not have a tributary stream, it was eliminated from the project.

Watershed Size- The next internal node identifies watershed size. If the watershed is less than 3 square miles or greater than 200 square miles then it was classified as a low priority. This is because experience has determined that most successful watershed initiatives are 10 to 12 digit watersheds (EPA, 2008). These range on average from 3 to 200 square miles. Interviews with watershed practitioners also suggest that watershed initiatives smaller than 3 square miles are difficult to implement. This is because community participation is limited. They also suggest that watershed initiatives larger than 200 square miles are difficult to implement because the large geographic area creates opportunities for multiple pollution sources and span across political lines and communities. This creates disconnect among citizen interests and organizations (T. Foster, personal communication, September 18, 2008). Therefore, watersheds that fall between 3 and 200 square miles appear to be optimum sizes for watershed management projects.

The watershed area was determined by delineation in StreamStats. The data layer and attribute table were saved in ArcMap. The analysis tool in ArcMap was used to select watersheds between 3 to 200 square miles (Figure20).

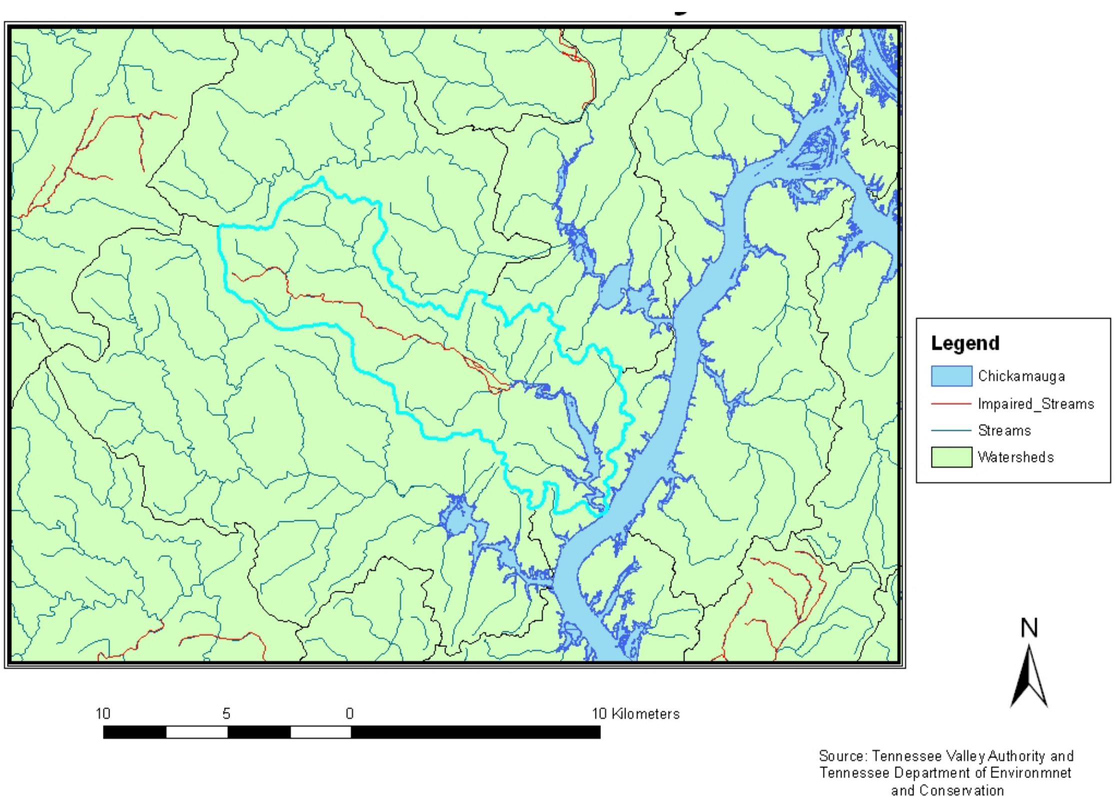


Figure 20. Selected Watersheds that were between 3 to 200 square miles

Embayment/ Watershed Ratio - This internal node helps determine the ratio of embayment size to watershed size. It is thought that embayments with very large watersheds receive considerable more water quality impacts than do smaller watersheds. Larger watersheds have more runoff which could contribute large amounts of nutrients, sediments, and other material to the embayment (Holdren et al, 2001). In addition, smaller embayments with large watersheds have shorter residence time. This would have the tendency to flush out the pollutants fast. In general it has been considered that in natural lakes, an embayment to watershed ratio less than or equal to 10% indicates a large watershed (Holdren et al, 2001). Input from TVA watershed practitioners suggested that this ratio should significantly be reduced for reservoirs. Reservoir embayments tend to be smaller and residence times tend to be shorter than natural lakes. Reservoirs are continuously discharging water for power generation and water supply. No rules were developed for embayment to watershed ratios for reservoirs. Therefore, to determine how to handle the ratios in the decision tree, ratios for all 96 embayments were analyzed. First the ratios were viewed in a histogram (Figure 21), where it was determined that the ratios were skewed to the left, indicating that most of the ratios fell below 5%. The data were then analyzed for frequency (Appendix A), which indicated that 50% of the data fell below 2%. With this information the decision was made, for this project, a ratio $\leq$ 0.5% (10% of the data) is a low priority and a ratio of $\leq$ 1% (20% of all embayments) is a low to moderate priority. Any embayment greater than 1% is a higher priority in the decision tree. The cut off for these priorities were also compared to and adjusted using the TVA's Chickamauga study and their ranking for embayments. If the cut off did not seem reasonable or did not match up with the Chickamauga rankings it was adjusted. This decision focuses on identifying embayments that have large watersheds and longer residence times.

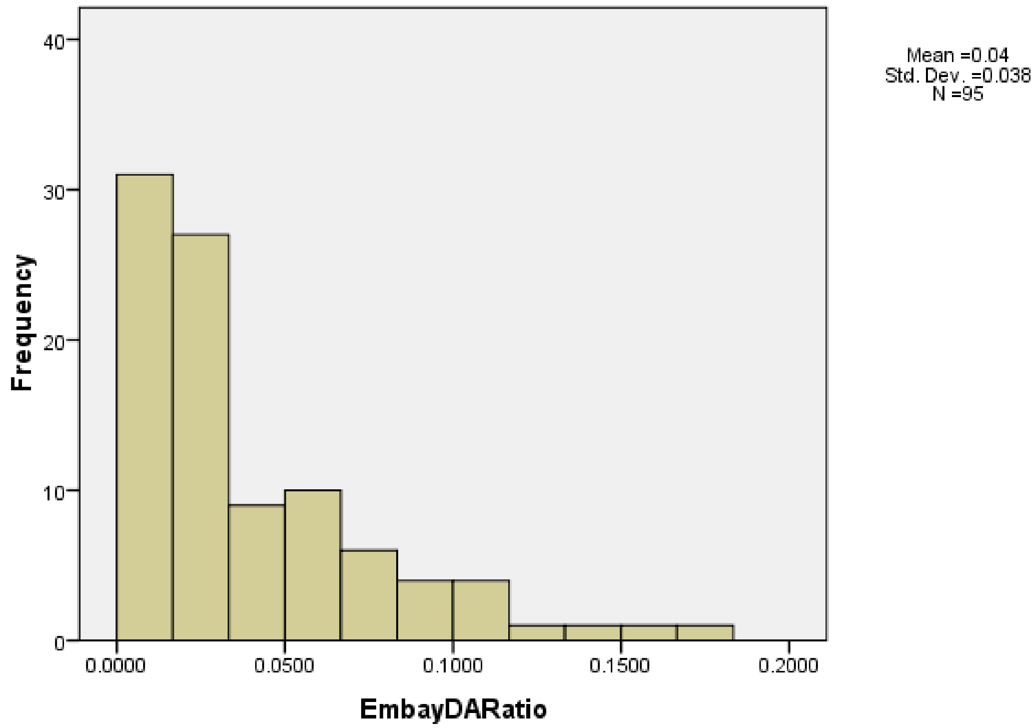


Figure 21. Histogram for embayment to watershed ratios for all 96 embayments in this study.

As previously mentioned the embayments were delineated in ArcMap and the embayment watersheds were delineated using StreamStats. Embayment and watershed areas were compiled in the ArcMap attribute table. The Field Calculator tool was then used to calculate the ratio (embayment area-watershed area) (Figure 22).

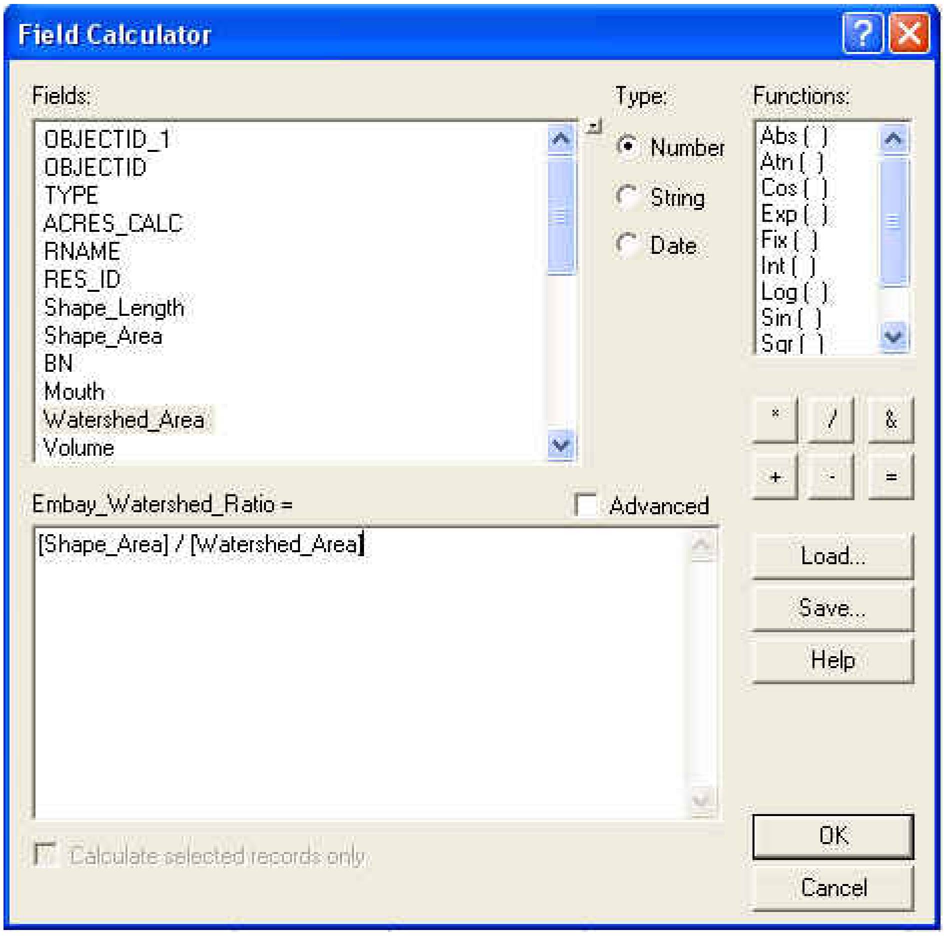


Figure 22: Calculation of embayment-watershed ratio

(adapted from ArcMap 9.2, January 18, 2009)

Maximum Residence Time - This internal node helps estimate a maximum residence time. As mentioned before, residence time is the amount of time it takes for water flowing into the embayment to flow out of the embayment. This is determined by taking the volume of the embayment and dividing it by the flow entering in from the drainage area. The longer the residence time the more likely the embayment water quality will be impacted. Residence time is not easily obtained. Volume has to be determined, which can be accomplished by taking transects with sonar or it can be estimated using bathymetric maps. This project used maps to estimate maximum depth and used ArcMap to obtain the surface area of the embayment. A volume index was then estimated by multiplying embayment area X maximum depth X 0.80 (.80 accounts for 80% of the embayment area). Then to obtain an inflow, TN StreamStats was used to generate a minimum three day flow over a 2-year period. It would be better to have an estimated annual flow but StreamStats was not able to generate those data. Because minimal flow is being used, the estimation is a maximum residence time. This was calculated by multiplying embayment area X maximum depth X 0.80 / minimum flow/ 86,400 days, which provides maximum residence time in days. This may be an order of magnitude higher than residence times estimated by annual flow rates, but this is used as an index.

As with embayment and watershed ratio no standards were established for maximum residence time for impacting water quality. Residence time data were analyzed for all 96 embayments. A histogram was generated (Figure 23), which indicated that the data was skewed to the left, most of the data fell below 1,000 days. Then a frequency analysis was conducted (Appendix B), which indicated that 30% of the data falls below 600 days. Because the data have not been calibrated, this project is conservative, selecting a $\leq$ 70 days residence time (encompasses 5% of data) to be a low to moderate priority. A $\leq$ 180 day residence time (encompasses 10% of data) is considered a moderate priority. Any embayment with a maximum residence time greater than 180 days is at least a moderate priority. As with embayment-watershed area ratio, priorities were calibrated by using TVA's Chickamauga study, aligning priorities with the

Chickamauga embayment ratings. This decision focuses on identifying embayments with longer residence times, with the assumption that longer residence times have negative impacts on water quality.

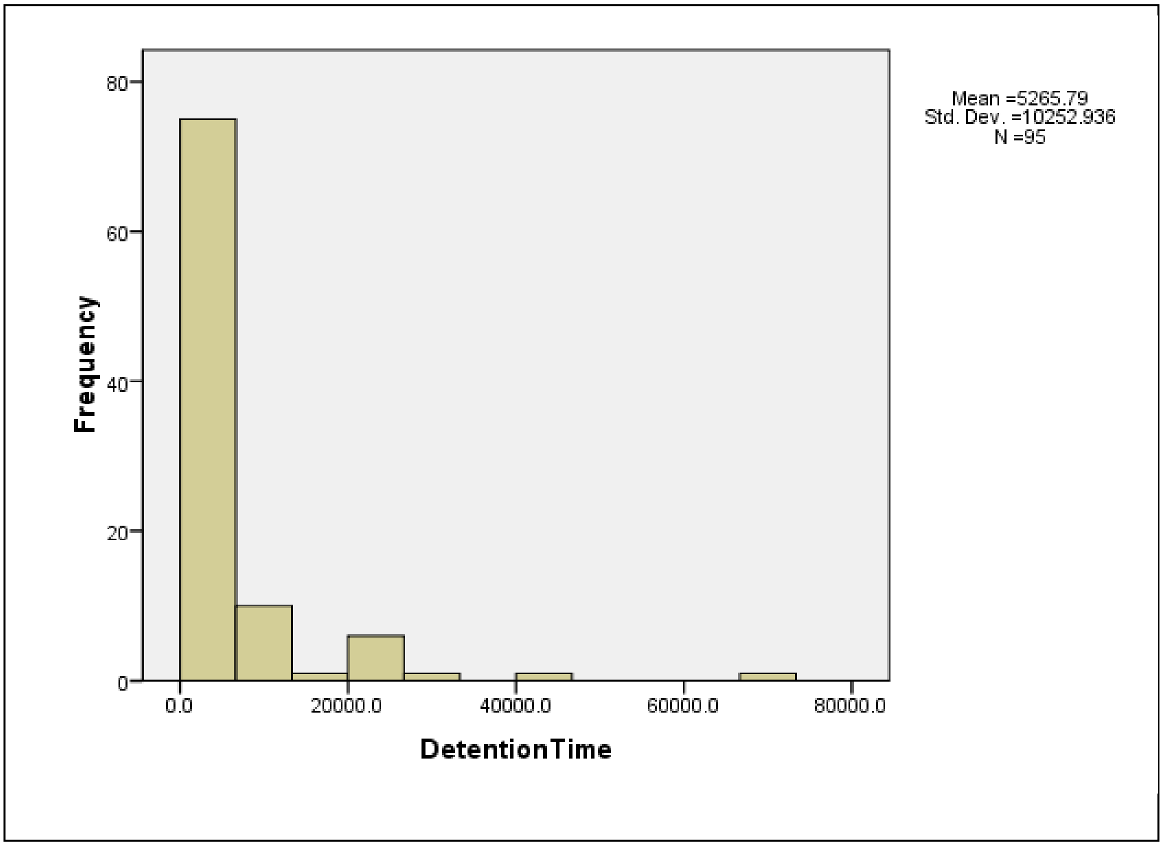


Figure 23. Histogram for maximum residence time (in days) for all 96 embayments.

Maximum depth was derived by using the bathymetry maps from Fishing Hotspots. Bathymetry data were overlaid on the embayments and maximum depth was identified (Figure 24). The maximum depth was then manually entered in the database attribute table. ArcMap was used to obtain the surface area of the embayment. An estimated volume was then determined. The inflow was determined by using TN StreamStats to generate a minimum 3-day flow over a 2-year period. Minimal flow was used to estimate maximum residence time.

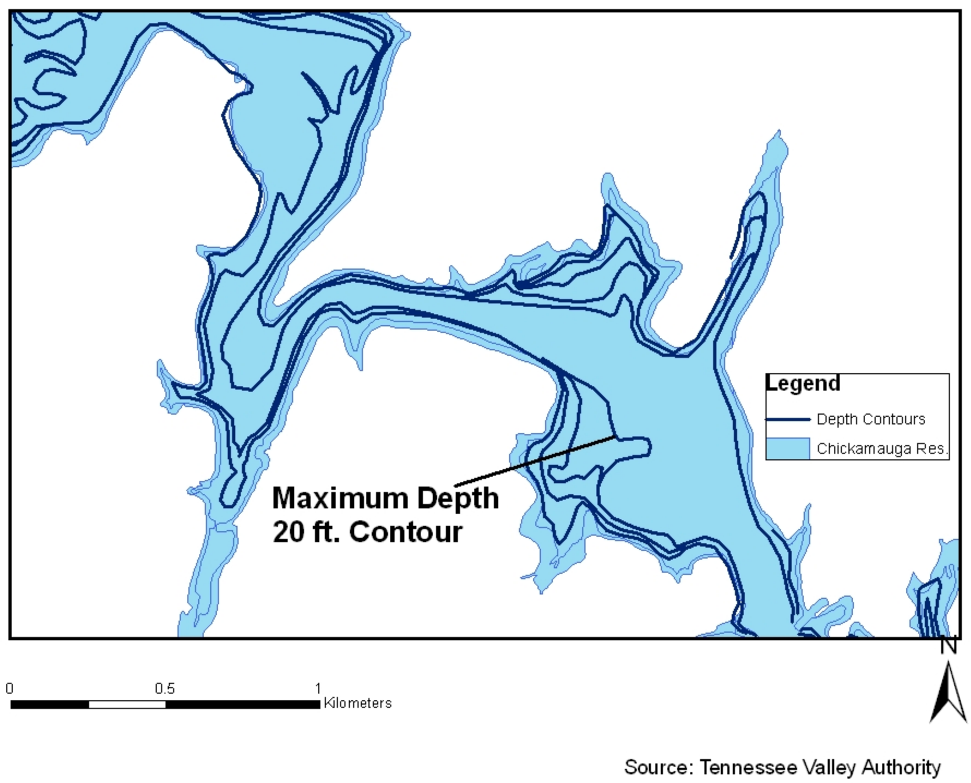


Figure 24. Example of how maximum depth was determined

Percentage of Impaired Streams - This node appears twice in the decision tree, it is both a internal node and terminal internal node leads to terminal nodes or the final prioritization. The state of Tennessee identifies streams that are impaired, meaning that they have sampled the stream and it does not meet its designated use. The stream impairment is an indicator that the watershed is contributing pollutants to the embayment. As with the decisions above, the decisions for the percentage of impaired streams are subjective. A histogram analysis was conducted to see the distribution for percentage of streams impaired in the watershed (Figure 25). The histogram identifies that the data are skewed to the left and the majority of the data falls below 25%. A frequency analysis showed that 50% of the data falls below 15% (Appendix C). Any embayment with a maximum residence time greater than 180 days but lacks impaired stream receives moderate priority. If $\leq$ 15% of the watershed has impaired streams, it receives a moderate to high priority. If the percentage of impaired streams is greater than 15%, then it receives a high priority. As previously mentioned, these priorities were calibrated by using TVA's Chickamauga study and using the Chickamauga embayment ratings as a means to determine priorities. Calibrations with the Chickamauga study lead to the creation of two nodes. Many embayments that were identified in the Chickamauga as impaired were eliminated due to the above root node, so an internal node in the beginning was created, which says any embayment with a percentage 30% or above automatically ranks as a high priority. Emabyments have a percentage lower than 30% follows the decision tree. This decision ultimately focuses on identifying embayments that are likely to be receiving a significant pollutant load.

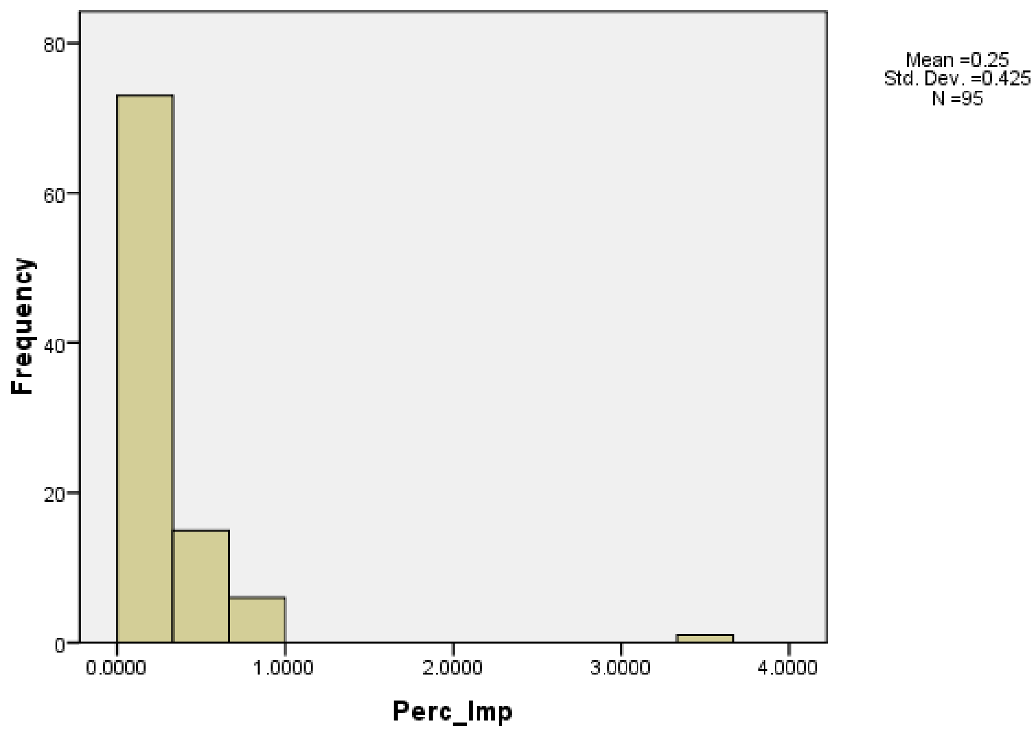


Figure 25. Histogram for percentage of impaired streams in all 96 embayments

The impaired tributary analysis was implemented in ArcMap. First, TDEC's 2008 impaired streams coverage was overlain on the reservoir base map. A buffer analysis was then applied to the impaired stream coverage (Figure 26). The buffer analysis extended a one half mile buffer on both sides of the impaired streams. This buffer size was selected and based on an Official Public Repository document compiled TVA, they state that the Tennessee Valley watershed encompasses 42, 910 square miles and there are 42,000 miles of stream in the watershed. This translates to about one square mile of watershed to one linear mile of stream (TVA, 2008). It is understood that this may vary with topography, but it provide a rough estimate. By using this estimation, the area of buffer could be compared to the embayment watershed area to give a rough estimate of percentage of impaired streams per watershed area.

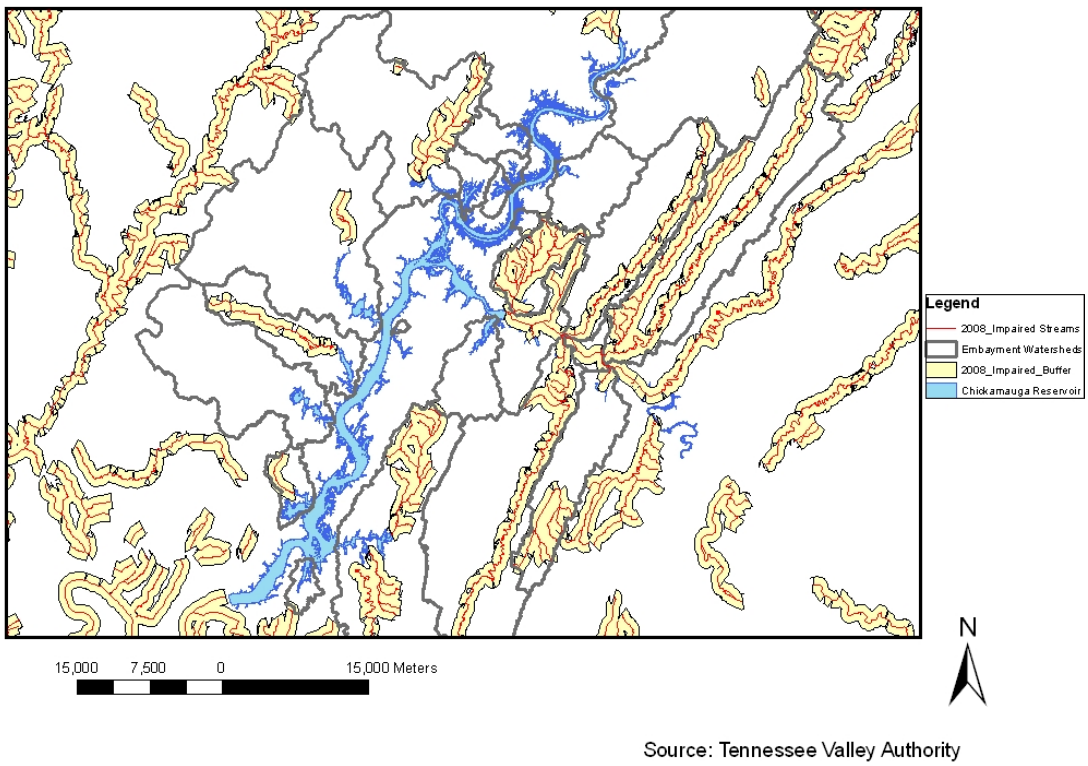
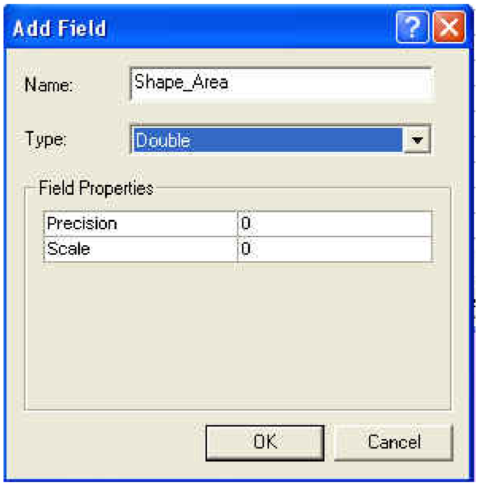


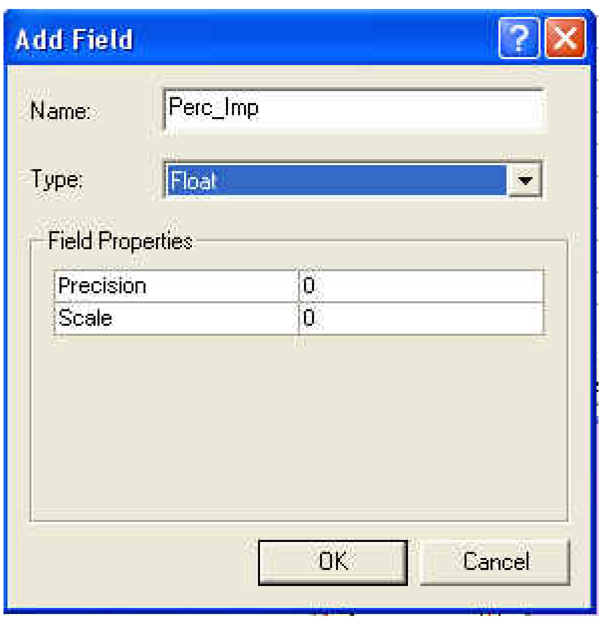
Figure 26. Buffer applied to impaired streams

To implement the stream buffer analysis in ArcMap, ArcTools was opened, the user navigated to “Analysis Tools,” “Overlay,” and “Intersect.” This opened the “Intersect” analysis tool where both the buffer and watershed coverages were both entered to be analyzed. The analysis cut the coverages where both intersected, creating an additional data coverage which identified all the impaired streams for each embayment watershed (Figure 26). Within that layer the attribute table was modified to include fields for both area of impaired stream (Shape_Area) (Figure 27) and percentage of impaired stream per watershed (Perc_Imp) (Figure 28). Properties for each field are listed below:



(adapted from ArcMap 9.2, January 18, 2009)

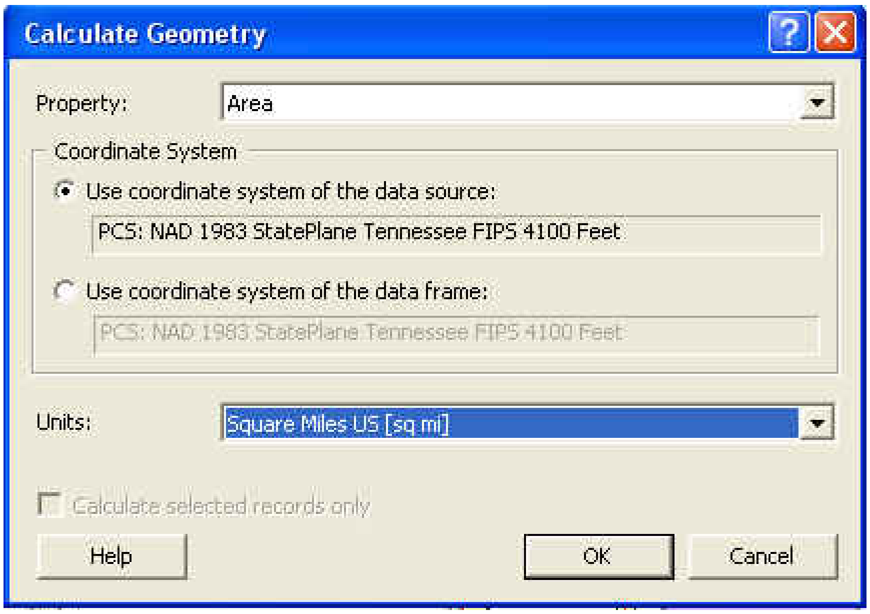
Figure 27. Properties of Shape_Area Field



(adapted from ArcMap 9.2, January 18, 2009)

Figure 28. Properties of Perc_Imp Field

The impaired stream area was calculated by selecting “Calculate Geometry” and choosing square miles for units (Figure 29). This calculated area of the impaired stream buffer for each embayment watershed.



(adapted from ArcMap 9.2, January 18, 2009)

Figure 29. Example of how to calculate area for the impaired stream buffer

The percent of impaired stream was calculated by selecting the Per_Imp field and “Field Calculator” option. While in the calculator, the impaired stream area (Shape_Area) was divide that by total embayment watershed area (Figure 30). This provided the percent of stream miles per embayment watershed area.

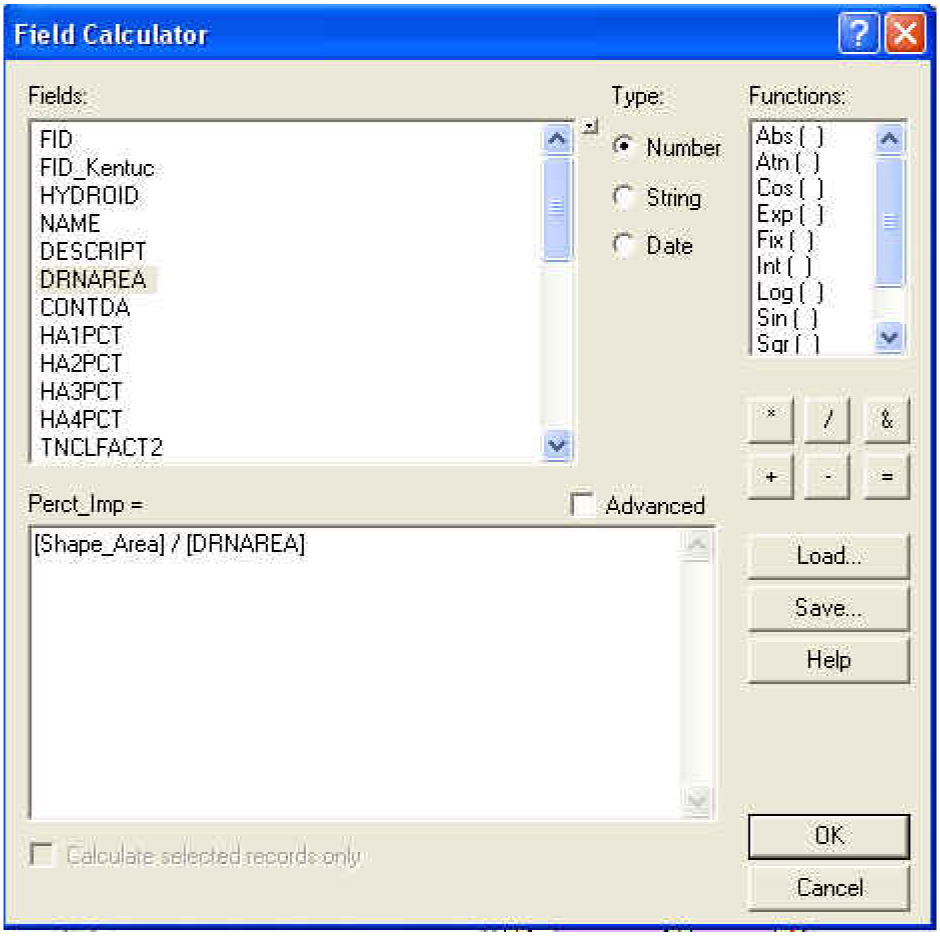


Figure 30. Calculation of percent of impaired stream miles per embayment watershed (adapted from ArcMap 9.2, January 18, 2009)

Trial Analysis

The first version of a decision tree was created in 2008. The earlier version was slightly different from the above decision tree but was used as the beginning test model. To test the decision tree model, it was applied to two reservoirs; Boone and Chickamauga. This was conducted to determine if the prioritization process would provide useable results. The first analysis used a decision tree that was based on the following hierarchy of criteria; presence of tributary stream, watershed size, embayment to reservoir area, flow restrictions, and water quality impairments. Presence of a stream was determined by the visually determining if a stream was present on a topographic map. The watershed size was delineated by digitizing in ArcMap and ArcMap calculated an estimated watershed size. ArcMap was also used to digitize and delineate embayments and calculate embayment area. The reservoir area was derived from reservoir maps obtained from TVA. Bottle necks (areas that restrict water flow through the embayment) were determined by using professional judgement, a TVA reservoir map was viewed to determine if there were roads or other physical features that would restrict flow from the embayment to the main reservoir. These restrictions could cause the residence time to be longer. Stream impairments were determined by overlaying a digital coverage of impaired streams (obtained from TDEC) over a topographic map and reservoir map. Percentage was calculated by estimating the number of impaired stream miles divided by an estimated total stream miles in the watershed.

Application of the decision tree identified 10 embayments as high priorities on Chickamauga reservoir and one priority embayment on Boone reservoir (Figures 31 and

32). These results were presented at the 2008 Tennessee AWRA, ETSU's Student Research Forum, and Appalachian Karst Symposium conference. Comments and feedback assisted in adjusting the model. Suggestions were to replace embayment-reservoir ratio with embayment-watershed ratio. This provides a better estimate of watershed input and also influences residence time. There was also a suggestion to replace flow restriction by residence time. These suggestions were discussed with the agency advisory committee and they agreed. Revisions were made and the final version can be seen above in the Decision Tree section of this report.

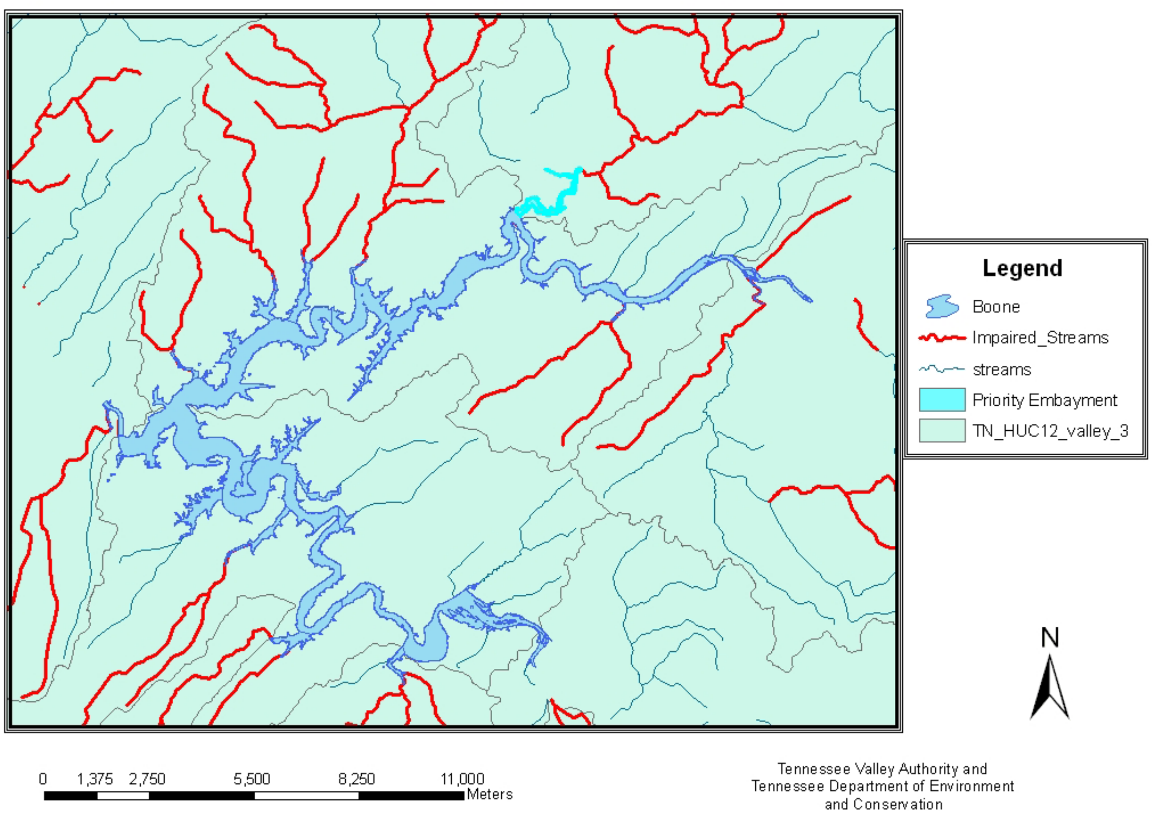


Figure 31. First Round - Prioritized embayments on Boone Reservoir

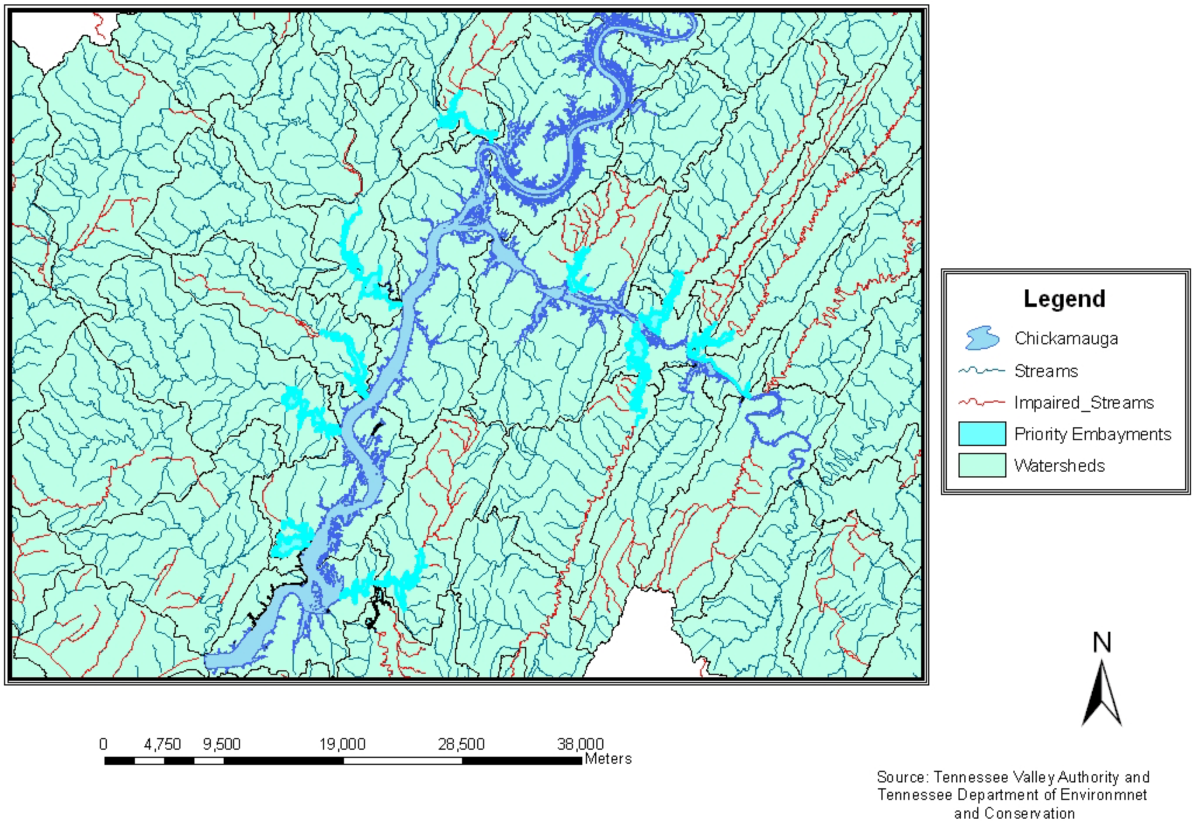


Figure 32. First Round - Prioritized embayments on Chickamauga Reservoir

CHAPTER 4

RESULTS

Prioritized Embayments

The decision tree analysis was applied to all 11 reservoirs. Prioritization is divided into five categories: Low, low to moderate, moderate, moderate to high, high. As previously mentioned these priorities were based histograms, frequency analysis, and comparisons to TVA's Chickamauga study and using the Chickamauga embayment ratings as a means to determine priorities. Each reservoir and the priority embayments are identified below.

In applying the decision tree model to Boone Reservoir, 4 out of 6 embayments were identified as high priorities (Figure 33). The other 2 were low priorities.

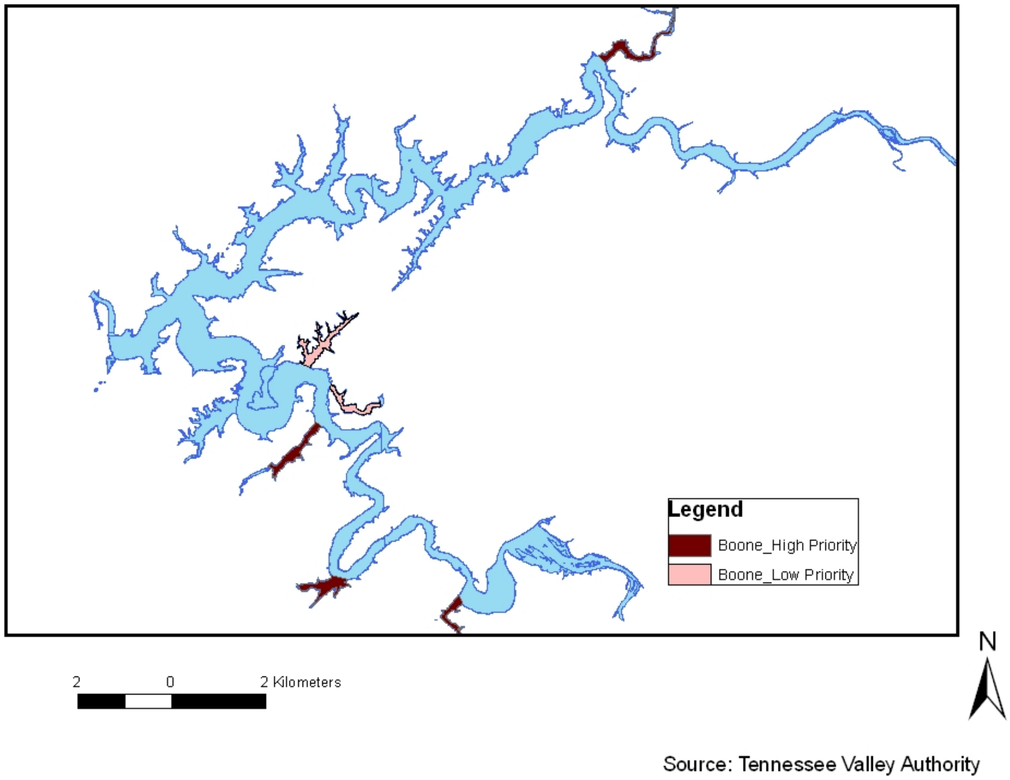


Figure 33. Prioritized Embayments on Boone Reservoir

In applying the decision tree model to Cherokee Reservoir; 9 embayments were assessed, 3 were a moderate priority, 5 were moderately-high priorities, and 1 was a high priority (Figure 34).

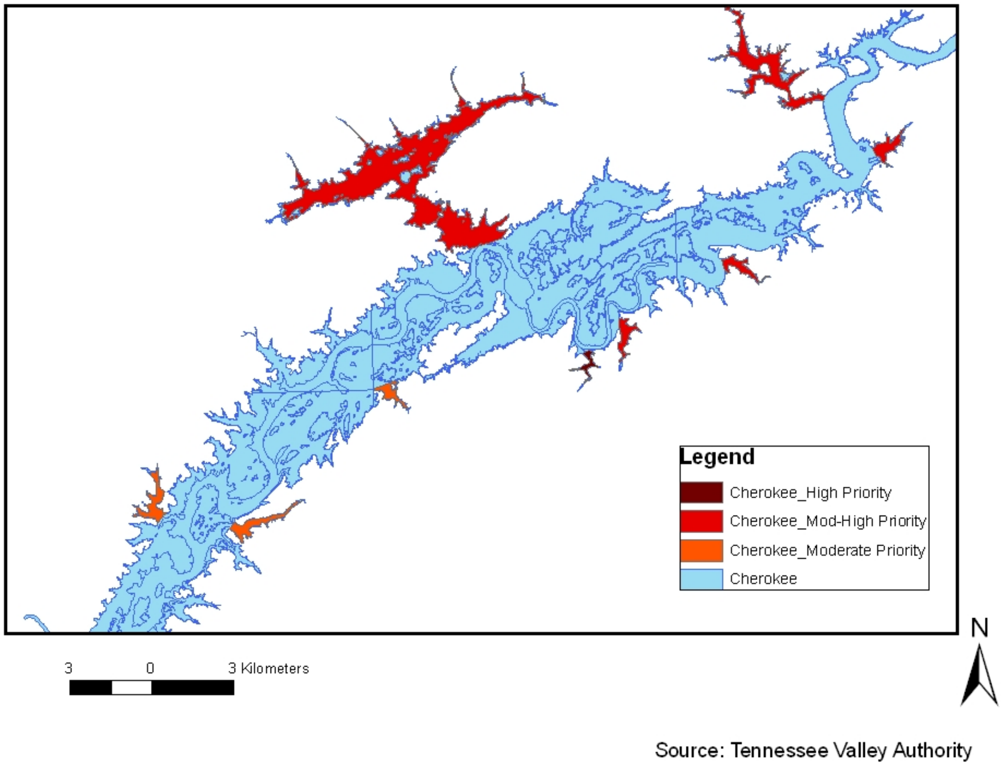


Figure 34. Prioritized Embayments on Cherokee Reservoir

In applying the decision tree model to Chickamauga Reservoir; 18 embayments were assessed, 2 were low to moderate priorities, 4 were moderate priorities, 5 were moderate to high priorities, and 7 were high priorities (Figure 35).

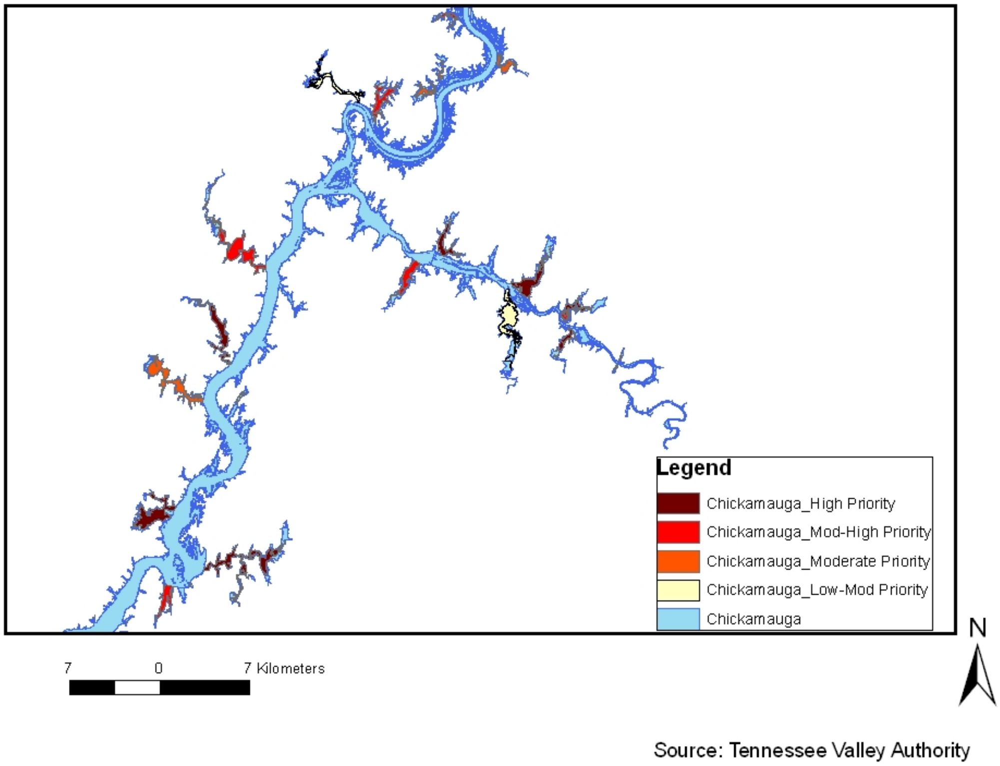


Figure 35. Prioritized Embayments on Chickamauga Reservoir

In applying the decision tree model to Douglas Reservoir; 6 embayments were assessed, 3 were moderate priorities, 2 were moderate to high priorities, and 1 was a high priority (Figure 36).

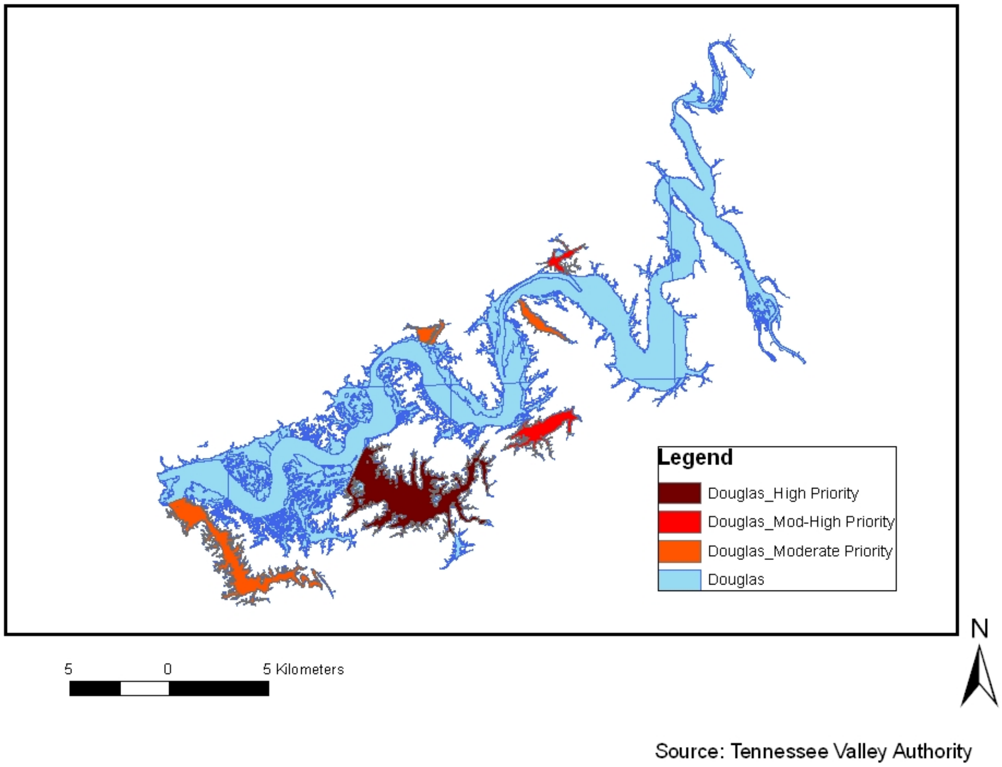


Figure 36. Prioritized Embayments on Douglas Reservoir

In applying the decision tree model to Ft. Loudoun Reservoir; 9 embayments were assessed and all 9 were high priorities (Figure 37).

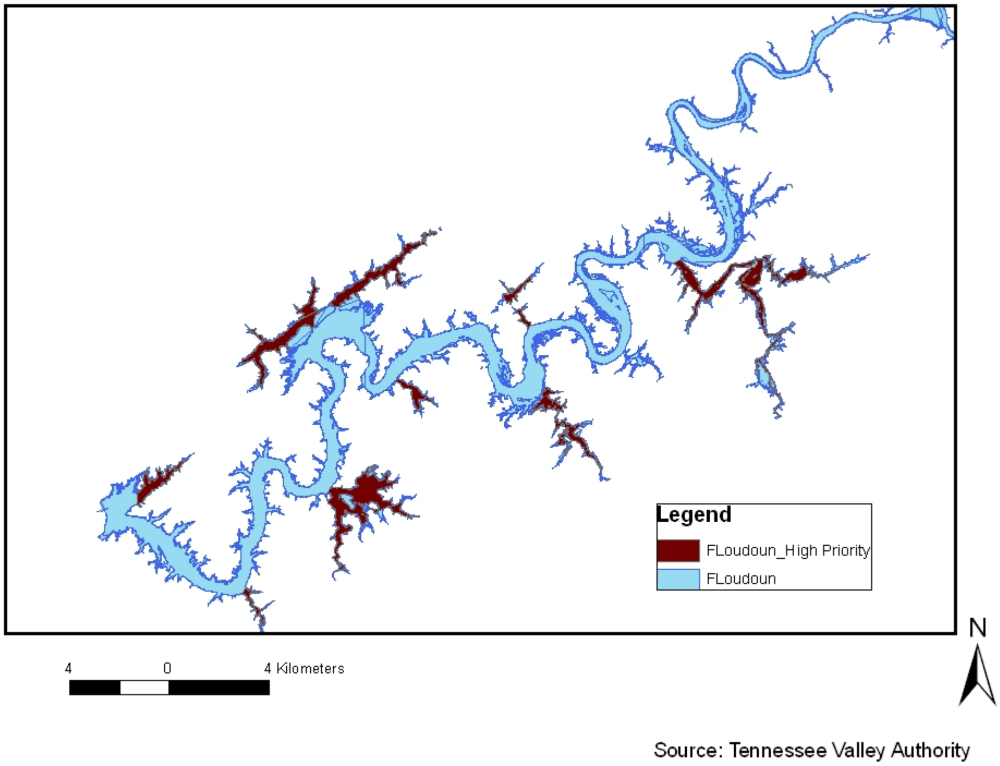


Figure 37. Prioritized Embayments on Ft. Loudoun Reservoir

In applying the decision tree model to Kentucky Reservoir; 4 embayments were assessed, 3 were moderate priorities and 1 was a moderately to high priority (Figure 38). There are several more embayments on Kentucky Reservoir but bathymetry data were not available to determine maximum residence time.

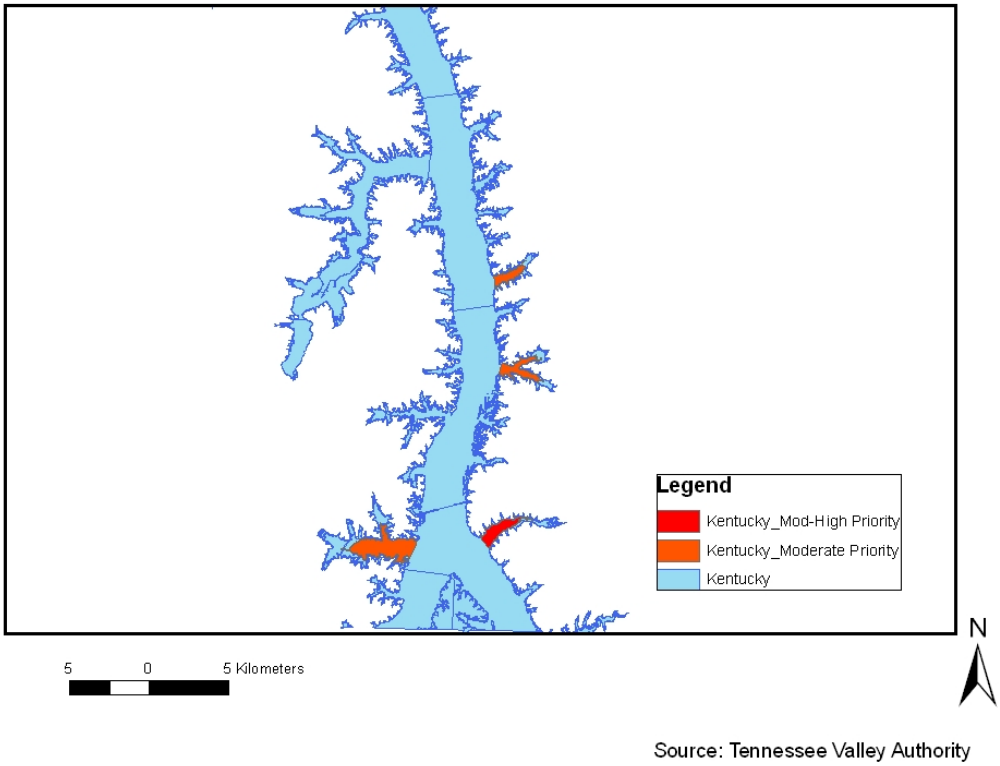


Figure 38. Prioritized Embayments on Kentucky Reservoir

In applying the decision tree model to Nickajack Reservoir; 1 embayment was assessed, it ranked as a moderate to high priority (Figure 39).

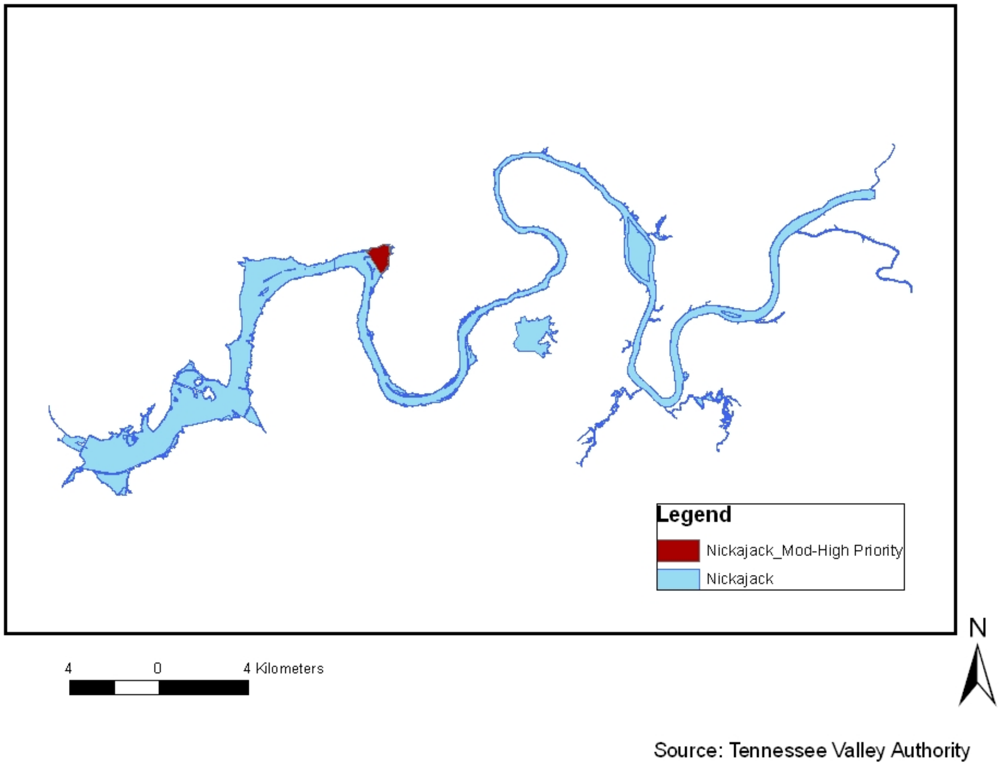


Figure 39. Prioritized Embayments on Nickajack Reservoir

In applying the decision tree model to Norris Reservoir; 17 embayments were assessed, 2 were low priorities, 2 were low to moderate priorities, 1 was a moderate priority, 1 was a moderate to high priority, and 11 were high priorities (Figure 40).

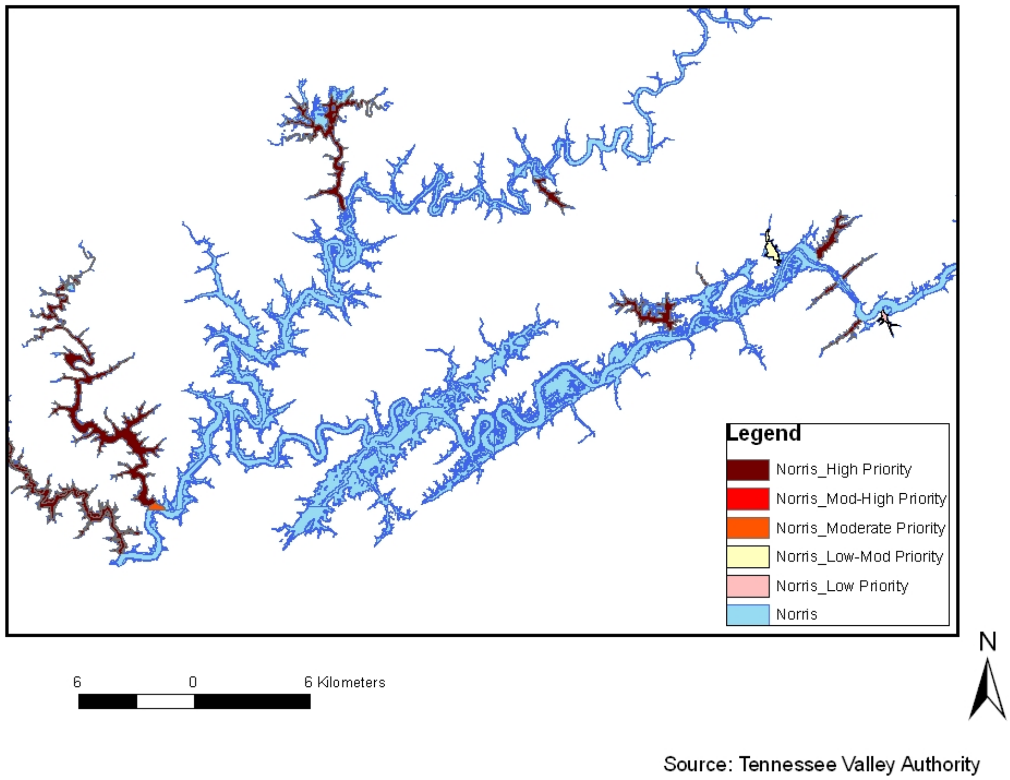


Figure 40. Prioritized Embayments on Norris Reservoir

In applying the decision tree model to Tellico Reservoir; 10 embayments were assessed, 2 were low priorities, 2 were low to moderate priorities, 1 was a moderately high priority, and 5 were high priorities (Figure 41).

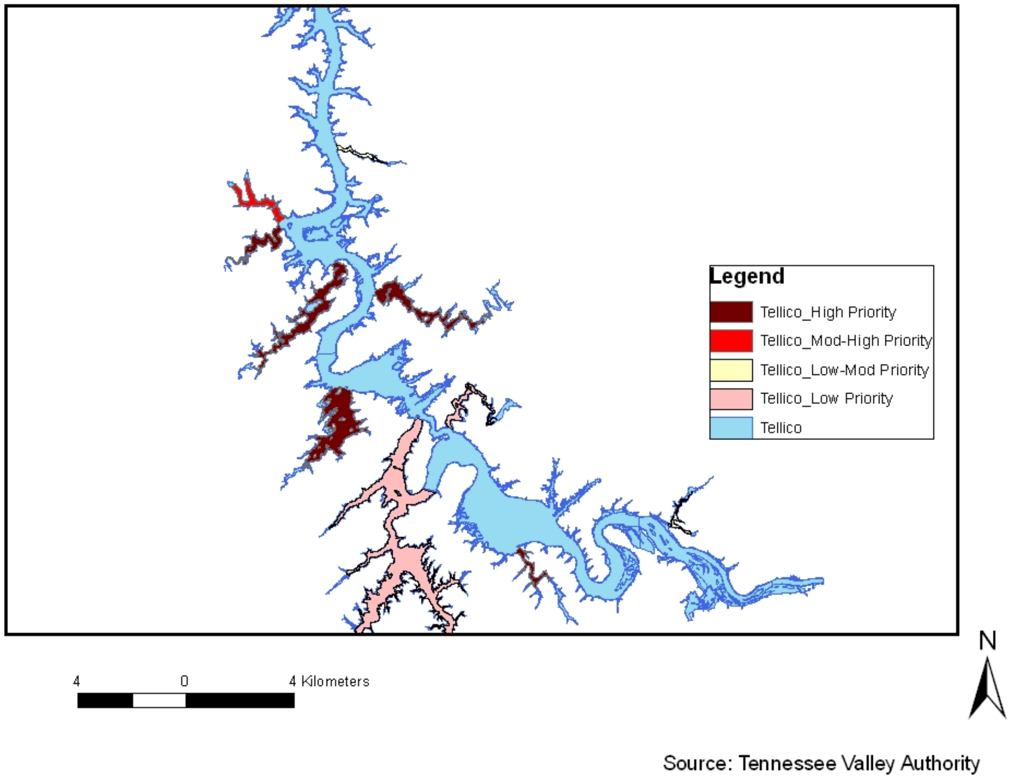


Figure 41. Prioritized Embayments on Tellico Reservoir

In applying the decision tree model to Tims Ford Reservoir; 9 embayments were assessed, 2 were low priorities, 5 were moderate priorities, 1 was a moderately high priority, and 1 was a high priority (Figure 42).

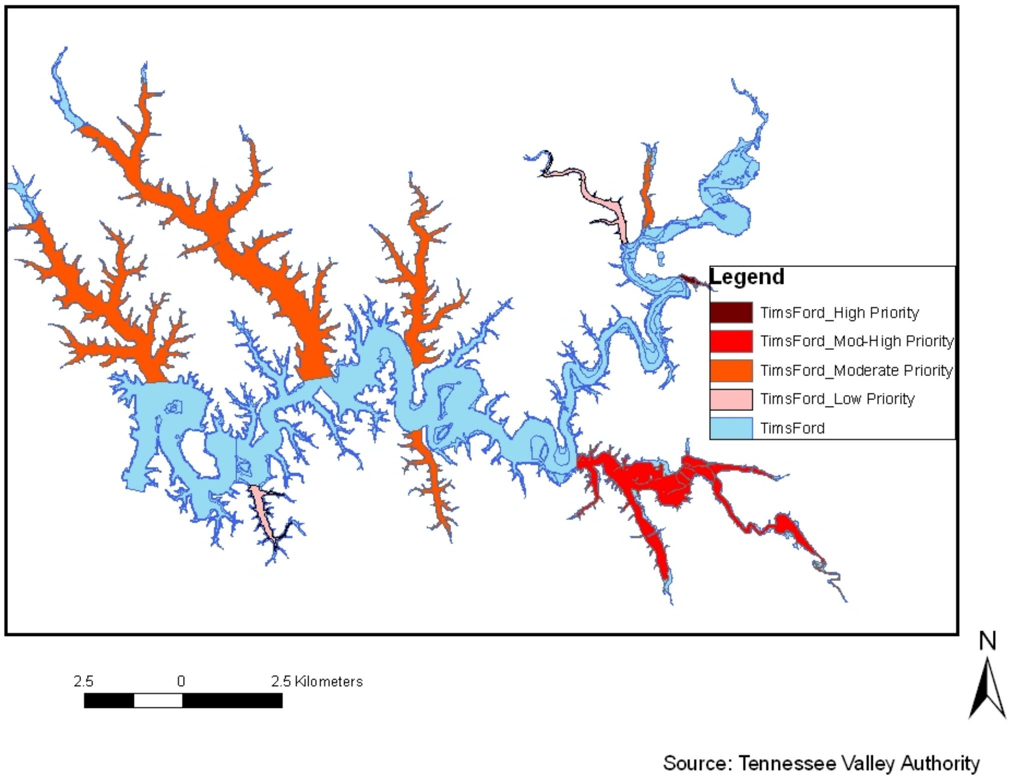
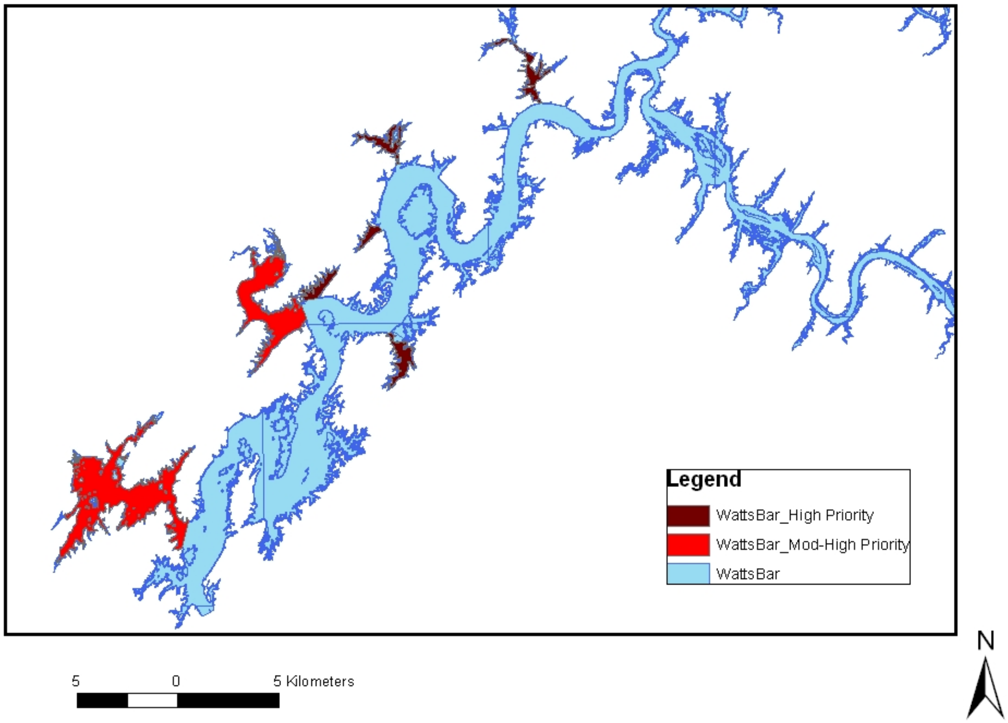


Figure 42. Prioritized Embayments on Tims Ford Reservoir

In applying the decision tree model to Watts Bar Reservoir; 7 embayments were assessed, 2 were moderately high priorities, and 5 were high priorities (Figure 43).



Source: Tennessee Valley Authority

Figure 43. Prioritized Embayments on Watts Bar Reservoir

Embayment Water Quality Monitoring

In 2005, TVA collected water quality data in several embayments throughout the Tennessee Valley (Figure 44). Assessments were conducted for Dissolved Oxygen (DO), Temperature, Nitrogen, Phosphorus, Chlorophyll-a, Suspended Sediment, pH, and Turbidity. For the purpose of this project, DO and Chlorophyll-a were the focus to verify the decision tree. DO and Chlorophyll-a are both good indicators of nutrient pollution. Usually, higher Chlorophyll-a concentrations indicate excessive nutrient loads. In addition, low DO indicate excessive nutrient loads (Holdren et al, 2001).

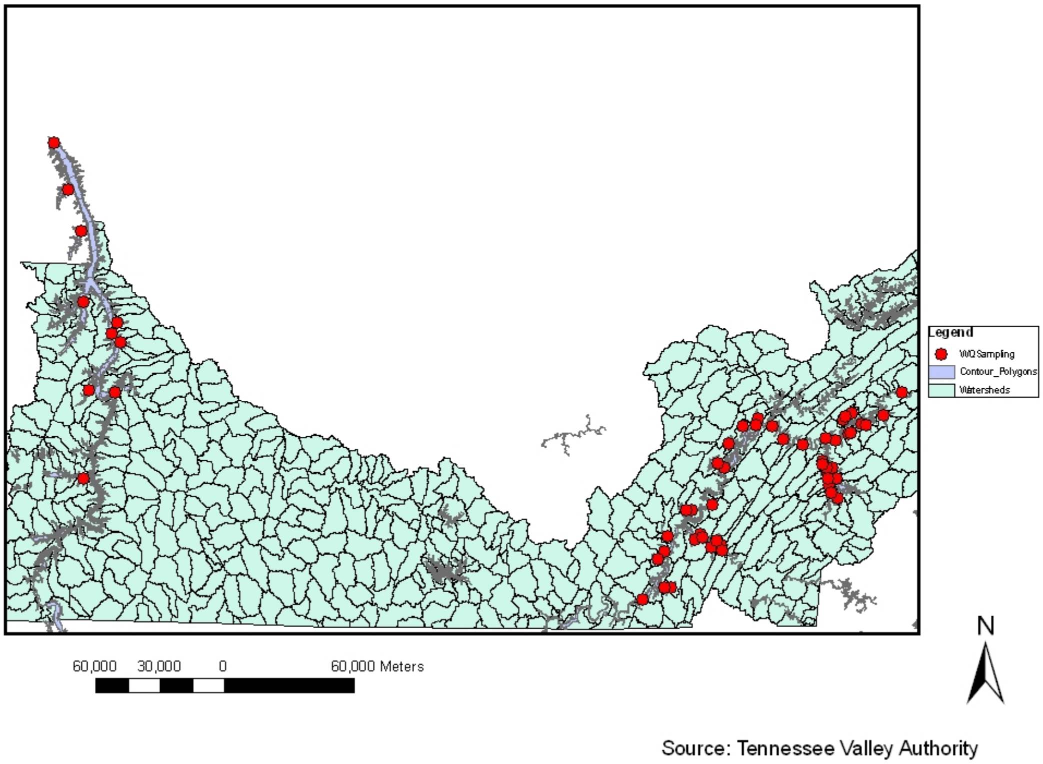


Figure 44. Water Quality Monitoring Locations

Five samples for DO and Chlorophyll-a were taken throughout the summer months (May-September) of 2005, one sample per month. The median values for each of these parameters were compared to the State of Tennessee water quality standards. The DO water quality criterion for fish and aquatic life in reservoirs is 5 mg/L (TDEC 2007). In comparing the mean values against this criterion, only one sample exceeded state standards, which was a DO of 4.8 in the Savannah embayment on Chickamauga Reservoir. This did not correspond to an embayment in this research. Even though, Chlorophyll-a does not have a state numeric standard, this project used the Recreational nutrient response criteria for Pickwick Reservoir, which is 18 microgram/liter of Chlorophyll-a (TDEC 2007). Over 10 embayments sampled exceeded this standard. In fact, 57% of the embayments that had a chlorophyll-a concentration of 18 microgram-liter or higher fell within the moderately high to high priority ranking of the decision tree (Table 3).

Table 3. Chlorophyll-a and Priority Ranking Comparison

Reservoir	Embayment	Corrected Chlorophyll-a	Priority Ranking
Chickamauga	Goodfield	17	moderate
Chickamauga	Sale	14	moderately-high
Chickamauga	Savannah	26	high
Chickamauga	Wolftever	22	high
Chickamauga	Rogers	17	high
Chickamauga	Soddy	11	moderate
Chickamauga	Gunstocker	18	moderately-high
Chickamauga	South Mouse	28	high
Chickamauga	Mud	19	moderately-high
Chickamauga	Possum	10	high
Chickamauga	Agency	19	high
Fort Loudoun	Lackey	22	high
Fort Loudoun	Little Turkey	21	high
Fort Loudoun	Turkey	16	high
Fort Loudoun	Ish	20	high
Tellico	Clear	12	moderately-high
Tellico	Baker	9	high
Tellico	Bat	12	high
Tellico	Island	9	high
Watts Bar	Whites	18	high
Watts Bar	Caney	22.5	high
Watts Bar	Piney	13	moderately-high
Watts Bar	Kings	21	high
Percent of embayments sampled that align with Moderately High (4) to High Priority (5)			57%

In addition to looking at state standards, correlation and regression analysis were applied to the water quality data and the decision nodes in the decision tree. In viewing the analysis no strong correlations exist.

CHAPTER 5

CONCLUSION

In an effort to simplify water quality improvement in reservoirs, this project has focused on improving water quality in reservoir embayments, which are smaller and more manageable units. They are prime locations to locate marinas, parks, beaches, and residential homes. In addition, embayments have smaller contributing watersheds, which makes it easier to identify causes and sources of pollution. Stakeholders are able to gain ownership and focus on their improvement activities.

The goal of this thesis was to review current data and information to determine which physical characteristics of embayments impact water quality. The data were assembled into a GIS-based database. Embayments of 11 main reservoirs were mapped and digitized in ArcGIS. Initial characterization criteria include watershed size, embayment area-watershed area ratio, depth, and stream influence on embayments. The characterization process was then applied to the mapped reservoir embayments in Tennessee to identify and prioritize embayments that are most likely to be affected by watershed restoration efforts. Ninety-five embayments were analyzed in the following reservoirs: Boone, Cherokee, Douglas, Watts Bar, Tellico, Fort Loudoun, Nickajack, Kentucky, Norris, Tims Ford, and Chickamauga. Over 28 embayments were identified as a high priority for water quality improvement effort. It was attempted to verify the decision tree analysis with existing water quality data. Initial correlation analysis could not verify the model. Simple comparisons were made between the Chlorophyll-a data and the decision tree ranks. Fifty-seven percent of the Emabyments with high

Chlorophyll-a concentrations aligned with moderately high to high priority embayments. This correlation is not enough to validate the model.

This project help develop a screening tool based on experience and literature. There was a lot of work accomplished in research, data compilation, and model development. It is obvious that more work needs to be conducted, especially water quality monitoring to validate the model. This was beyond the scope of this work. But this was a good first step. The long-term goal is to apply the model and calibrate it to create a more effective tool to identify and prioritize embayments for resource management.

Recommendations

The following guidelines are recommended to enhance the model and create a more effective tool for resource management.

1. Apply this model to all reservoirs in Tennessee. To accomplish this, a consistent set of information for all reservoirs should be identified. The current model only includes reservoirs that are located in the Tennessee Valley drainage.

2. Additional characteristics such as water quality data, land-use, and ecoregion data should be included in a phase two prioritization. The water quality, land-use would help determine pollutant loadings and ecoregion data could help adjust for different ranging environmental conditions across Tennessee.

3. Working with the USGS and the TN StreamStats model to determine annual flow for the embayment watersheds. This could assist in determining average residence time for the embayments, which is a major factor in affecting water quality.

4. Additional research should be conducted to determine more accurate decisions on the embayment-watershed ratios, maximum residence time, and percentage of impaired streams. For this research, assumptions were made based on histogram distribution and frequency analysis.

5. Conduct correlation analysis to better determine the physical characteristics that impact water quality in embayments. The characteristics chosen for the decision tree model in this project are based on experience and literature.

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APPENDICES

APPENDIX A

Frequency Analysis of Embayment-Watershed Ratios

EmbayDARatio

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	8.37E-4	1	1.1	1.1	1.1
	0.002423	1	1.1	1.1	2.1
	0.00263	1	1.1	1.1	3.2
	0.00307	1	1.1	1.1	4.2
	0.003077	1	1.1	1.1	5.3
	0.003651	1	1.1	1.1	6.3
	0.004209	1	1.1	1.1	7.4
	0.004548	1	1.1	1.1	8.4
	0.00483	1	1.1	1.1	9.5
	0.004863	1	1.1	1.1	10.5
	0.004926	1	1.1	1.1	11.6
	0.005128	1	1.1	1.1	12.6
	0.005575	1	1.1	1.1	13.7
	0.005967	1	1.1	1.1	14.7
	0.006093	1	1.1	1.1	15.8
	0.006829	1	1.1	1.1	16.8
	0.008556	1	1.1	1.1	17.9
	0.00896	1	1.1	1.1	18.9
	0.009275	1	1.1	1.1	20.0
	0.011007	1	1.1	1.1	21.1
	0.0115	1	1.1	1.1	22.1
	0.011863	1	1.1	1.1	23.2

0.01224	1	1.1	1.1	24.2
0.012817	1	1.1	1.1	25.3
0.013362	1	1.1	1.1	26.3
0.014237	1	1.1	1.1	27.4
0.014269	1	1.1	1.1	28.4
0.014363	1	1.1	1.1	29.5
0.015623	1	1.1	1.1	30.5
0.01602	1	1.1	1.1	31.6
0.016392	1	1.1	1.1	32.6
0.016758	1	1.1	1.1	33.7
0.016926	1	1.1	1.1	34.7
0.016966	1	1.1	1.1	35.8
0.018727	1	1.1	1.1	36.8
0.018855	1	1.1	1.1	37.9
0.01892	1	1.1	1.1	38.9
0.019281	1	1.1	1.1	40.0
0.019463	1	1.1	1.1	41.1
0.019721	1	1.1	1.1	42.1
0.02049	1	1.1	1.1	43.2
0.020643	1	1.1	1.1	44.2
0.020993	1	1.1	1.1	45.3
0.021298	1	1.1	1.1	46.3
0.021821	1	1.1	1.1	47.4
0.022207	1	1.1	1.1	48.4
0.022244	1	1.1	1.1	49.5
0.023761	1	1.1	1.1	50.5
0.023814	1	1.1	1.1	51.6
0.023987	1	1.1	1.1	52.6
0.025122	1	1.1	1.1	53.7
0.026202	1	1.1	1.1	54.7

0.026412	1	1.1	1.1	55.8
0.027811	1	1.1	1.1	56.8
0.028346	1	1.1	1.1	57.9
0.030399	1	1.1	1.1	58.9
0.031128	1	1.1	1.1	60.0
0.031555	1	1.1	1.1	61.1
0.035284295	1	1.1	1.1	62.1
0.03729	1	1.1	1.1	63.2
0.038331	1	1.1	1.1	64.2
0.043798	1	1.1	1.1	65.3
0.044154	1	1.1	1.1	66.3
0.045134	1	1.1	1.1	67.4
0.045674	1	1.1	1.1	68.4
0.045872	1	1.1	1.1	69.5
0.049332	1	1.1	1.1	70.5
0.050106	1	1.1	1.1	71.6
0.050916	1	1.1	1.1	72.6
0.051588	1	1.1	1.1	73.7
0.052335	1	1.1	1.1	74.7
0.053335	1	1.1	1.1	75.8
0.055555	1	1.1	1.1	76.8
0.061092	1	1.1	1.1	77.9
0.063292	1	1.1	1.1	78.9
0.063523	1	1.1	1.1	80.0
0.064134	1	1.1	1.1	81.1
0.06703	1	1.1	1.1	82.1
0.069324	1	1.1	1.1	83.2
0.072104	1	1.1	1.1	84.2
0.075456	1	1.1	1.1	85.3
0.078891	1	1.1	1.1	86.3

	0.080609	1	1.1	1.1	87.4
	0.088109	1	1.1	1.1	88.4
	0.089074	1	1.1	1.1	89.5
	0.091243	1	1.1	1.1	90.5
	0.098726	1	1.1	1.1	91.6
	0.10114	1	1.1	1.1	92.6
	0.110705	1	1.1	1.1	93.7
	0.11302	1	1.1	1.1	94.7
	0.114891	1	1.1	1.1	95.8
	0.132632	1	1.1	1.1	96.8
	0.145578	1	1.1	1.1	97.9
	0.151653	1	1.1	1.1	98.9
	0.179855	1	1.1	1.1	100.0
	Total	95	100.0	100.0	

APPENDIX B

Frequency Analysis of Maximum Residence Time in days

ResidenceTime

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	34.51949561	1	1.1	1.1	1.1
	38.53244559	1	1.1	1.1	2.1
	49.89392382	1	1.1	1.1	3.2
	58.57876203	1	1.1	1.1	4.2
	69.90737851	1	1.1	1.1	5.3
	89.40779903	1	1.1	1.1	6.3
	95.49006112	1	1.1	1.1	7.4
	107.3780595	1	1.1	1.1	8.4
	126.1009822	1	1.1	1.1	9.5
	178.9152215	1	1.1	1.1	10.5
	190.6487583	1	1.1	1.1	11.6
	229.9785241	1	1.1	1.1	12.6
	245.1034803	1	1.1	1.1	13.7
	256.4832391	1	1.1	1.1	14.7
	291.9095253	1	1.1	1.1	15.8
	299.7106546	1	1.1	1.1	16.8
	322.9598353	1	1.1	1.1	17.9
	326.2149099	1	1.1	1.1	18.9
	346.4678558	1	1.1	1.1	20.0
	354.2859605	1	1.1	1.1	21.1
	393.6128706	1	1.1	1.1	22.1
	408.0126487	1	1.1	1.1	23.2
	417.7904076	1	1.1	1.1	24.2
	425.965561	1	1.1	1.1	25.3

479.3573796	1	1.1	1.1	26.3
512.4775693	1	1.1	1.1	27.4
565.0767808	1	1.1	1.1	28.4
588.9238285	1	1.1	1.1	29.5
644.6978023	1	1.1	1.1	30.5
645.4704801	1	1.1	1.1	31.6
651.211541	1	1.1	1.1	32.6
677.5830847	1	1.1	1.1	33.7
691.6909145	1	1.1	1.1	34.7
700.7331047	1	1.1	1.1	35.8
740.0526898	1	1.1	1.1	36.8
761.3894784	1	1.1	1.1	37.9
788.0860424	1	1.1	1.1	38.9
844.2169563	1	1.1	1.1	40.0
1027.560109	1	1.1	1.1	41.1
1155.812953	1	1.1	1.1	42.1
1159.157873	1	1.1	1.1	43.2
1160.510729	1	1.1	1.1	44.2
1167.491718	1	1.1	1.1	45.3
1196.468305	1	1.1	1.1	46.3
1314.555926	1	1.1	1.1	47.4
1429.433771	1	1.1	1.1	48.4
1886.670227	1	1.1	1.1	49.5
1894.905418	1	1.1	1.1	50.5
1976.092194	1	1.1	1.1	51.6
1998.635877	1	1.1	1.1	52.6
2035.242187	1	1.1	1.1	53.7
2170.429563	1	1.1	1.1	54.7
2184.811907	1	1.1	1.1	55.8
2218.720759	1	1.1	1.1	56.8

2329.823763	1	1.1	1.1	57.9
2345.204147	1	1.1	1.1	58.9
2431.630323	1	1.1	1.1	60.0
2459.002932	1	1.1	1.1	61.1
2630.147671	1	1.1	1.1	62.1
2845.654815	1	1.1	1.1	63.2
2963.067361	1	1.1	1.1	64.2
3024.818173	1	1.1	1.1	65.3
3187.793544	1	1.1	1.1	66.3
3205.269059	1	1.1	1.1	67.4
3476.563949	1	1.1	1.1	68.4
3625.710534	1	1.1	1.1	69.5
3922.279651	1	1.1	1.1	70.5
3936.646414	1	1.1	1.1	71.6
4597.34431	1	1.1	1.1	72.6
4601.439699	1	1.1	1.1	73.7
5046.323604	1	1.1	1.1	74.7
5136.494236	1	1.1	1.1	75.8
5396.995712	1	1.1	1.1	76.8
5744.138854	1	1.1	1.1	77.9
6553.870929	1	1.1	1.1	78.9
6784.727429	1	1.1	1.1	80.0
6846.053834	1	1.1	1.1	81.1
6894.261587	1	1.1	1.1	82.1
7135.848415	1	1.1	1.1	83.2
7448.558036	1	1.1	1.1	84.2
7804.886426	1	1.1	1.1	85.3
8042.670739	1	1.1	1.1	86.3
9544.472227	1	1.1	1.1	87.4
10089.001	1	1.1	1.1	88.4

	13320.91451	1	1.1	1.1	89.5
	14555.13213	1	1.1	1.1	90.5
	20580.22544	1	1.1	1.1	91.6
	21567.06652	1	1.1	1.1	92.6
	21880.25358	1	1.1	1.1	93.7
	23502.17199	1	1.1	1.1	94.7
	24149.64364	1	1.1	1.1	95.8
	24463.67997	1	1.1	1.1	96.8
	27832.05117	1	1.1	1.1	97.9
	45243.25419	1	1.1	1.1	98.9
	72479.75472	1	1.1	1.1	100.0
	Total	95	100.0	100.0	

APPENDIX C

Frequency Analysis of Percent Impaired Streams

Perc_Imp

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	0	22	23.2	23.2	23.2
	0.00773	1	1.1	1.1	24.2
	0.008546	1	1.1	1.1	25.3
	0.013107	1	1.1	1.1	26.3
	0.014919	1	1.1	1.1	27.4
	0.017908	1	1.1	1.1	28.4
	0.030614	1	1.1	1.1	29.5
	0.031924	1	1.1	1.1	30.5
	0.036454	1	1.1	1.1	31.6
	0.039478	1	1.1	1.1	32.6
	0.041361	1	1.1	1.1	33.7
	0.04457	1	1.1	1.1	34.7
	0.050218	1	1.1	1.1	35.8
	0.050842	1	1.1	1.1	36.8
	0.052817	1	1.1	1.1	37.9
	0.059402	1	1.1	1.1	38.9
	0.064249	1	1.1	1.1	40.0
	0.073845	1	1.1	1.1	41.1
	0.078428	1	1.1	1.1	42.1
	0.080102	1	1.1	1.1	43.2
	0.094595	1	1.1	1.1	44.2
	0.104777	1	1.1	1.1	45.3
	0.106677	1	1.1	1.1	46.3
	0.117008	1	1.1	1.1	47.4

0.118282	1	1.1	1.1	48.4
0.122703	1	1.1	1.1	49.5
0.15334	1	1.1	1.1	50.5
0.161283	1	1.1	1.1	51.6
0.161547	1	1.1	1.1	52.6
0.164035	1	1.1	1.1	53.7
0.185006	1	1.1	1.1	54.7
0.212598	2	2.1	2.1	56.8
0.220167	1	1.1	1.1	57.9
0.225292	1	1.1	1.1	58.9
0.235492	1	1.1	1.1	60.0
0.24443	2	2.1	2.1	62.1
0.249028	1	1.1	1.1	63.2
0.251753	1	1.1	1.1	64.2
0.253929	1	1.1	1.1	65.3
0.268663	1	1.1	1.1	66.3
0.271348	1	1.1	1.1	67.4
0.274185	1	1.1	1.1	68.4
0.277622	1	1.1	1.1	69.5
0.291009	1	1.1	1.1	70.5
0.297711	1	1.1	1.1	71.6
0.30696	1	1.1	1.1	72.6
0.31261	1	1.1	1.1	73.7
0.323783	1	1.1	1.1	74.7
0.328451	1	1.1	1.1	75.8
0.328804	1	1.1	1.1	76.8
0.338614	1	1.1	1.1	77.9
0.344424	1	1.1	1.1	78.9
0.360289	1	1.1	1.1	80.0
0.371997	1	1.1	1.1	81.1

	0.382247	1	1.1	1.1	82.1
	0.440449	1	1.1	1.1	83.2
	0.440597	1	1.1	1.1	84.2
	0.460774	1	1.1	1.1	85.3
	0.485368	1	1.1	1.1	86.3
	0.526353	1	1.1	1.1	87.4
	0.546886	1	1.1	1.1	88.4
	0.551056	1	1.1	1.1	89.5
	0.595616	1	1.1	1.1	90.5
	0.608913	1	1.1	1.1	91.6
	0.651503	1	1.1	1.1	92.6
	0.795269	1	1.1	1.1	93.7
	0.796666	1	1.1	1.1	94.7
	0.81433	1	1.1	1.1	95.8
	0.865739	1	1.1	1.1	96.8
	0.9002	1	1.1	1.1	97.9
	0.938621	1	1.1	1.1	98.9
	3.63713	1	1.1	1.1	100.0
	Total	95	100.0	100.0	

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